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State of Deep-Sea Coral and Sponge Ecosystems in the Gulf of Mexico Region: Texas to the Florida Straits

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STATE OF DEEP-SEA CORAL AND SPONGE ECOSYSTEMS IN THE GULF OF MEXICO REGION: TEXAS TO THE FLORIDA STRAITS

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I. Introduction

This chapter provides an update and summary of the current state of knowledge of deep (> 50 m) azooxanthellate coral and sponge communities on hard-bottom habitats in the northern Gulf of Mexico (GoM) from the U.S.-Mexico border to the Florida Straits. This is an update since the first State of Deep-Sea Coral Ecosystems of the U.S. report (Lumsden et al. 2007) on the GoM by Brooke and Schroeder (2007)[1]. The chapter will focus on new material but also touch on some additional background information important in the context of deep corals and sponges not presented in 2007.

The GoM is unique in many ways, partly due to its unusual geological history and the resulting physiographic features that provide substrate for deep corals and sponges. The deep Gulf, from the outer portions of the continental shelf near 150 m depth across the continental slope to some of the deepest portions near 3,000 m depth, is generally considered one of the most geologically complex continental slopes in the world (Figure 1). The geological complexity of the GoM supports a high diversity of deep corals, each adapted to different environmental conditions (described

[1]The 2007 GoM report (Brooke & Schroeder 2007) also included information on the Florida Straits up to Biscayne Bay on the east coast of Florida. This geographic area is covered in the Southeast U.S. chapter of the current volume.

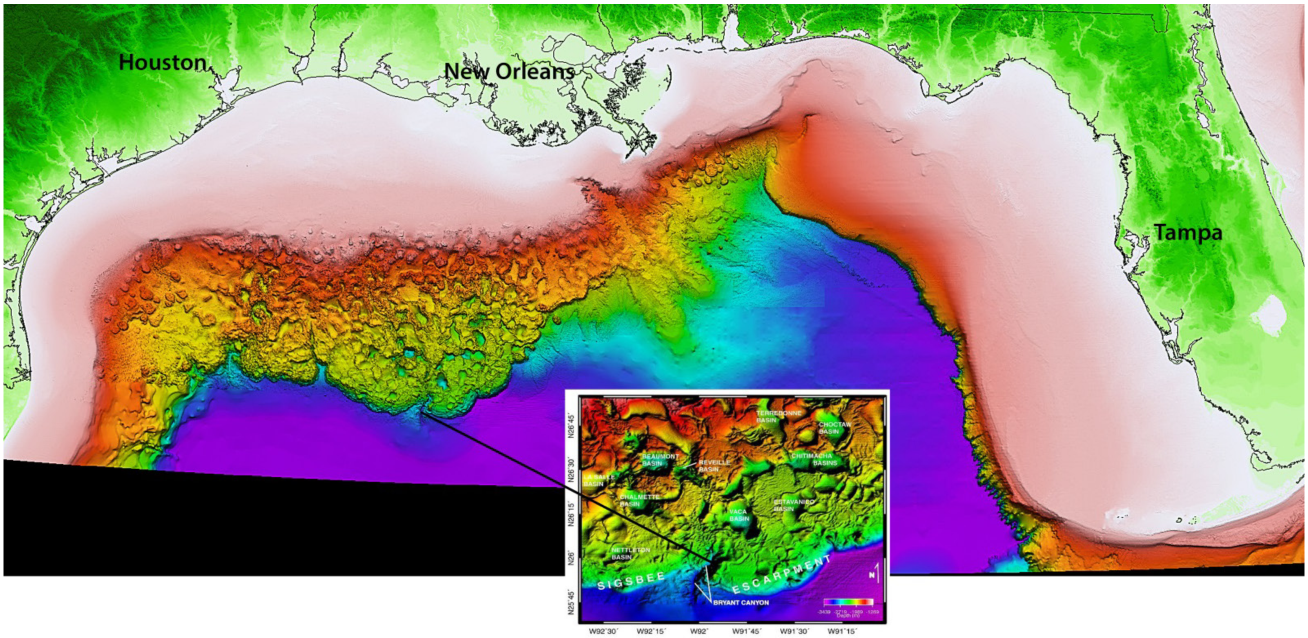

Figure 1. *Multibeam bathymetry of the northern Gulf of Mexico with depth shading of continental slope below 100 m showing the complexity of the slope. Created from industry-acquired 3-D seismic data processed at 50-ft. bin size by the Bureau of Ocean Energy Management. Inset shows the Sigsbee Escarpment.*

broadly in Roberts et al. 2009). The vast majority (> 99%) of the substrate in the central and western portion of the deep northern GoM is composed of soft sediments in mixtures of fine sand, silt and clay (Rowe & Kennicutt 2009). Sea pens, cup corals and bamboo corals can occur in soft sediments, occasionally in high abundance over a large area (Gallaway et al. 1988, Rowe & Kennicutt 2009). However, the highest diversity of large structure-forming coral and sponge epifauna tends to occur on hard bottom. In the mesophotic zone (30-150 m), some of the limited hard substrate is of biogenic origin (e.g. drowned Pleistocene coral reefs). Many other areas on the continental shelf are influenced by movement of underlying salt deposits that can raise the seabed to form banks or mounds where in some cases, such as the Flower Garden Banks, diverse zooxanthellate coral communities can develop. In one location, the only known example, basalt spires form a volcanic chimney that is exposed at Alderdice Bank. Hard-bottom habitats below 200-300 m are primarily the result of diapirism of Jurassic-age salt associated with trapping and migration of hydrocarbons.

Salt diapirism or 'salt tectonics' produced hundreds of banks and mounds along the continental slope in the northern region (west of the Florida Escarpment), because salts typically are buoyant relative to overlying sediments. Fissures in sediment overlying salt domes can allow trapped hydrocarbons to seep upwards to the seafloor which become a food source for bacterial chemosynthesis at the seep interface resulting in deposition of authigenic (generated in place) carbonates which can form large rocky features with moderate relief and patchy distribution. Carbonates either develop above the soft bottom substrate or become exposed over time. Carbonate structures associated with former and extant hydrocarbon seeps provide substantial habitat for deep corals and sponges in the northern GoM shelf and slope region (CSA 2007, Brooks et al. 2016).

In contrast, the Florida platform and escarpment along the eastern Gulf were formed by deposition and consolidation of sediments created by a variety of mechanisms including deposition by carbonate-producing organisms such as corals and mollusks (Hine 2009). The Bureau of Ocean Energy Management (BOEM) subdivides the GoM into three operational areas; Western, Central and Eastern (termed Planning Areas), each with different levels of industrial development and agency mission-oriented research investment (although many studies are ecosystem-based and include Gulf-wide locations and objectives). The northern central GoM (Central Planning Area) is historically the most active for research and exploration. Due to a moratorium on drilling offshore, the eastern GoM is less explored.

Since the last State of Deep-Sea Coral Ecosystems report (Brooke & Schroeder 2007) there has been an increase in exploration and research of the deep coral and sponge assemblages of the West Florida shelf and slope. Although data are limited, explorations to date suggest that the extent of hard-bottom habitat is large and the abundance and diversity of corals and sponges is high.

II. New Exploration and Research

Research on deep corals in the GoM has intensified substantially over the last decade. Since 2007, at least 52 research cruises have taken place in this region (Tables 1-2). A number of large multidisciplinary interagency projects have greatly expanded the number of known deep coral habitats in the GoM, and increased our knowledge of their distribution and community structure, as well as dispersal, growth and reproduction of key species.

Federally sponsored explorations of the deep GoM were planned for 2008-2012, but the 2010 GoM oil spill resulting from the blowout of the Macondo well and the sinking of *Deepwater Horizon* (DWH) drilling platform at a depth of 1,522 m was a major environmental event with profound ramifications for research and management. One effect of the spill was a dramatic increase in research effort as part of the federally mandated Natural Resource Damage Assessment (NRDA) for DWH. NRDA conducted multi-year investigations of deep corals in the mesophotic zone (depth range 65-90 m), and in the deep-sea (depth 1500 m and more). These studies included investigations of coral associated communities of fish, red crabs, infaunal and epifaunal invertebrates in surrounding soft sediments.

Table 1. *Research expeditions targeting deep-sea coral and sponge habitats in the Gulf of Mexico since 2007.*

Date	Vessel	Underwater vehicle	Sites	Notes
Mesophotic Coral Habitat Exploration by Flower Garden Banks National Marine Sanctuary				
Mar. 2007	M/V *Carolyn Choest*	HOV *Argus/NR1*	Horseshoe, Rankin/Bright, EFG and WFG,	Secrets of the Gulf Expedition - Dr. Robert Ballard
May 2009	R/V *Manta*	ROV *Phantom*	Stetson, McGrail and MacNeil Banks	
May 2010	R/V *Manta*	ROV *Phantom*	EFG and WFG	NCCOS
May 2011	R/V *Manta*	ROV *Phantom*	EFG and WFG	NCCOS
Aug.-Sep. 2012	R/V *Manta*	ROV *Phantom*	EFG and WFG	NCCOS
Oct. 2013	R/V *Manta*	ROV Mohawk	EFG	
Jul. 2015	R/V *Manta*	ROV Mohawk	McGrail, Bright and Geyer Banks	FAU/CIOERT/Voss Lab
Jul. 2015	R/V *Manta*	ROV Mohawk	Stetson Bank	Stetson Bank LTM
Jul. 2015	R/V *Manta*	ROV Mohawk	EFG, Horseshoe, Rankin, Bright, Rezak, Elvers, Sidner, Bouma, Bryant, Alderdice and Parker Banks	
BOEM/NOAA OER; Chemo III 3rd Field Sampling Expedition				
Jun.-Jul. 2007	*R/V Ronald H. Brown*	ROV *Jason II*	Chemo III primary sites, GB697, AT320, GC852, GB647, GC645, AC601	Spectacular *Madrepora* colonies at 1,400 m at GC852
BOEM/NOAA OER; Lophelia II				
Sep.-Oct. 2008	R/V *Nancy Foster*	ROV *Sea Vision*	4 shipwrecks, 13 coral sites	
Jun.-Jul. 2009	R/V *Brooks McCall*	AUV *Sentry*	8 coral sites	
Aug.-Sep. 2009	R/V *Ronald H. Brown*	ROV *Jason II*	5 shipwrecks, 12 coral sites	10 new coral sites
Oct.-Nov. 2010	R/V *Ronald H. Brown*	ROV *Jason II*	2 shipwrecks, 15 coral sites	5 new coral sites, first observation of corals impacted by *Deepwater Horizon* spill at block MC294.
Jul. 2012	R/V *Brooks McCall*	ROV *Kraken II*	5 deep-water oil and gas structures	4 surface structures, 1 subsea installation
USGS Collaboration Expeditions for Lophelia II				
Oct. 2008	R/V *Nancy Foster*	ROV *Sea Vision*	VK826, 862/906, West Florida Shelf	
Sep. 2009	R/V *Seward Johnson*	*HOV Johnson Sea Link*	VK826, 862/906, West Florida Shelf	
Sep.-Oct. 2010	R/V *Cape Hatteras*	ROV *Kraken II*	VK826, 862/906, West Florida Shelf	
Oct. 2010	R/V *Arctic Sunrise*	HOV *Dual DeepWorker*	VK862/906	Lander deployment
Oct.-Nov. 2011	R/V *Ronald H. Brown*	ROV *Jason II*	West Florida Shelf	
Oct.-Nov. 2011	R/V *Tommy Munroe*	ROV *Global Explorer*	VK862/906	Lander recovery
Florida Shelf Edge Exploration (FloSEE); NOAA OER, Cooperative Institute for Ocean Exploration, Research and Technology				
Jul. 2010	R/V *Seward Johnson*	HOV *Johnson Sea Link*	West Florida Shelf to Alabama	
Sep. 2011	R/V *Nancy Foster*	ROV *Kraken II*	West Florida Shelf to Alabama	
Ecosystem Impacts of Oil & Gas Inputs to the Gulf (ECOGIG); Ocean Exploration Trust				
Jul. 2013	E/V *Nautilus*	ROV *Hercules*	All Gulf	
Jun. 2014	E/V *Nautilus*	ROV *Hercules*	All Gulf	
Apr.-May 2015	E/V *Nautilus*	ROV *Hercules*	All Gulf	
BOEM study; Deep-Water Reconnaissance of Potentially Sensitive Biological Features				
Oct. 2011	R/V *Manta*	ROV *Phantom*	Horseshoe and 29 Fathom Banks	
Sep. 2012	R/V *Manta*	ROV *Phantom*	Rankin and 28 Fathom	
Sep. 2012	R/V *Manta*	ROV *Phantom*	28 Fathom, Bright, Geyer	
Apr. 2013	R/V *Manta*	ROV *Phantom*	Alderdice and Rezak	
Apr.-May 2013	R/V *Manta*	ROV *Phantom*	Rezak, Bouma, Sonnier	
Jun. 2013	R/V *Manta*	ROV *Phantom*	Elvers and McGrail	
Jun. 2013	R/V *Manta*	ROV *Phantom*	Sidner and Parker	

Table 1. *continued*

Date	Vessel	Underwater vehicle	Sites	Notes
Gulf of Mexico Exploration; NOAA OER				
Apr. 2012	E/V *Okeanos Explorer*	ROV *Deep Discoverer*	Northwest Gulf	EX1202
May 2012	E/V *Okeanos Explorer*	ROV *Deep Discoverer*	Florida Escarpment and Straits, Northeast Gulf	EX1203
Apr. 2014	E/V *Okeanos Explorer*	ROV *Deep Discoverer*	All Gulf	EX1402
Gulf of Mexico Exploration; *Alvin*				
Apr.-May 2014	R/V *Atlantis II*	HOV *Alvin*	North central Gulf	Science mission on deep coral and chemosynthetic community sites
Schmidt Ocean Institute Exploration, Mapping and Long-Term Effects of the DWH Spill				
Aug. 2012	R/V *Falkor*	ROV *Global Explorer*	Northeast Gulf	Deep-sea coral shakedown expedition
Sep. 2012	R/V *Falkor*	ROV *Global Explorer*	Northwest Gulf, Texas Banks	Mapping of South Texas Banks
Nov. 2012	R/V *Falkor*	ROV *Global Explorer*	Northwest Gulf	Long-term effects of DWH spill
General Exploration; Ocean Exploration Trust				
Mar. 2012	R/V *Maria S. Merian*	ROV *Cherokee*	West and southwest Florida slope	General cold-water coral ecosystem exploration including other areas in southern GoM and outside GoM
Jul. 2014	E/V *Nautilus*	ROV *Hercules*	All Gulf	Exploring the unknown Gulf of Mexico

Table 2. *Research expeditions after* Deepwater Horizon *spill to assess deep-water coral damages.*

Date	Vessel	Underwater Vehicle	Sites	Notes
Natural Resources Damage Assessment Cruises				
Jul. 2010	R/V *Nancy Foster*	ROV *Global Explorer*	VK sites and MC751	
Aug. 2010	R/V *Nancy Foster*	ROV *Global Explorer*	Alabama Alps, Roughtongue Reef, Coral Trees Reef	Mesophotic reef assessment
Nov. 2010	R/V *Brooks McCall*	Drift Camera	Well site and MC334	MC344 corals discovered
Mar. 2011	HOS *Sweetwater*	Industry ROV	MC294 and MC118	
Apr. 2011	R/V *McArthur*	AUV *Sentry*	Well site vicinity	5 new sites found
Aug. 2011	M/V *Holiday Choest*	UHD Shilling Robotics	Alabama Alps, Roughtongue Reef, Yellowtail Reef, Coral Trees Reef, Madison-Swanson South Reef	Mesophotic reef assessment
Oct. 2011	M/V *Holiday Choest*	UHD Shilling Robotics	previously discovered sites	
Jun.-Jul. 2014	R/V *Walton Smith*	ROV *Global Explorer*	Alabama Alps, Roughtongue Reef, Yellowtail Reef, Coral Trees Reef, Madison-Swanson South Reef, Madison-Swanson North Reef	Mesophotic reef assessment
ECOGIG Expeditions (Ecosystem Impacts of Oil and Gas Inputs to the Gulf - Part of Gulf of Mexico Research Initiative)				
Nov. 2012	R/V *Falkor*	ROV *Global Explorer*	Impacted and control sites	Additional exploration
Jun. 2013	R/V *Nautilus*	ROV *Hercules*	Impacted and control sites	Additional exploration
Jun.-Jul. 2014	R/V *Nautilus*	ROV *Hercules*	Impacted and control sites	Additional exploration
Other Cruises Associated with Damage Assessment				
Dec. 2010	R/V *Atlantis*	HOV *Alvin, AUV Sentry*	Return to MC294 and MC344	
Mar. 2012	E/V *Okeanos Explorer*	ROV *Deep Discoverer*	Portion of virtual cruise, previous coral sites	Additional exploration

Each of the relevant major developments will be discussed in more detail below. New deep coral research since 2007 can be divided into three broad categories.

- Continental slope studies; applied science and exploration missions (Table 1);
- Continental shelf studies of mesophotic reef habitats (Table 1);
- DWH-related response and NRDA cruises (Table 2).

II.1. Continental Slope Studies

II.1.i – Large Federal Interdisciplinary Studies

Two large federal multidisciplinary deep-water studies have been completed since 2007, sponsored by the National Oceanographic Partnership Program (NOPP) and funded by BOEM and the National Oceanic and Atmospheric Administration (NOAA) through the Office of Exploration and Research (OER). The intention of these studies was to conduct research that addresses the needs of BOEM, which is charged with regulating the development of oil and gas resources in the deep GoM in an environmentally sound manner. The exploratory mission and other agency objectives of NOAA OER were also met. These studies had complimentary projects separately funded by United States Geological Survey (USGS), and are briefly described below:

1) Investigations of chemosynthetic communities on the lower continental slope of the GoM, (Chemo III): 2005-2009

This multidisciplinary study was initiated by partners BOEM and NOAA OER in 2005 to investigate both chemosynthetic and coral communities at depths below 1,000 m. This depth zone had received little research effort because regional submergence facilities (e.g., the *Johnson Sea Link* submersibles) were limited to ~1,000 m depth. Three major cruises were conducted during the Chemo III study including the use of the *Alvin* manned submersible and the remotely operated vehicle (ROV) *Jason II*. At most of the 13 primary study sites there were observations of at least a few large colonial cnidarians; however, only one site (in lease block GC852) visited during this study was found to have a diverse coral community. This site included three species of scleractinian structure-forming corals (*Madrepora oculata*, *Enallopsammia rostrata* and *Solenosmilia variabilis*) at a depth of 1,435 m (Brooks et al. 2014, Brooks et al. 2016).

In a related study, USGS partners conducted a series of cruises (2006–2009) visiting a subset of Chemo III stations. This research incorporated a variety of additional research topics, including tropho-dynamics of fish populations and mid-water trawl collections above deep coral communities to investigate connectivity. USGS researchers also returned to a shallower deep coral site within Viosca Knoll lease block 826 (VK826, 500-700 m). This is a well-known deep coral site that was a primary focus during the earlier Lophelia I research program (funded by

BOEM) from 2004-2007 (CSA 2007). The USGS cruises included additional study sites at Viosca Knoll, Atwater Canyon, Alaminos Canyon, and Green Canyon (Demopoulos et al. 2010, Ross et. al. 2012).

2) Exploration and research of northern GoM deep-water natural and artificial hard-bottom habitats with emphasis on coral communities: reefs, rigs and wrecks (Lophelia II): 2008-2012

Lophelia II was the second of the BOEM and NOAA OER studies on deep coral ecosystems in the GoM, and this represented a continuation and expansion of Lophelia I. As with the previous BOEM studies, Lophelia II brought together numerous collaborating groups and again partnered with USGS to continue the exploration and research of deep coral communities in the deep GoM (Brooks et. al. 2016). Lophelia I spanning 2004-2007 was referenced in Brooke and Schroeder (2007) but the report was final in July 2007 (CSA 2007).

The partnership between federal and academic scientists included exploration and research at three different types of deep-water habitats: natural reefs, shipwrecks and offshore energy platforms in water depths ranging from 300 to 2,700 m. One primary goal of the study was to develop a robust capability for predicting the occurrence of rich cnidarian hard-bottom communities in the deep GoM, with emphasis on scleractinian coral assemblages. In addition, long-term monitoring stations were established to study change over time along with laboratory experiments to provide a more comprehensive understanding of the processes that control the occurrence and distribution of *Lophelia pertusa* in the GoM (Larcom et al. 2014, Lunden et al. 2014, Brooks et al. 2016).

A total of five Lophelia II cruises (eight including USGS cruises) were completed between 2008 and 2012 (Table 1). During these cruises, researchers discovered new coral-dominated sites on the northern GoM slope and the west Florida Escarpment, documented coral colonization of shipwrecks and deep-water offshore platforms, and documented changes at sites discovered during Lophelia I. The shipwreck and platform components of the Lophelia II study represented important additions to the understanding of coral habitats. Eight wreck sites were surveyed to depths of over 2,100 m, in addition to those described previously (Brooke & Schroeder 2007, Church et al. 2007). Many had extensive coral cover (Larcom et al. 2014, Brooks et al. 2016). A total of 24 natural habitat study sites were surveyed with an ROV during the project. Community structure, biodiversity and biogeography of corals and associates were addressed by different techniques including photographic transects, photo mosaics, quantitative collections of community components and molecular methods.

Lophelia II had strong collaboration with USGS scientists, which was highlighted on the USGS Discovre Program website[2]. A series of reports

[2]http://fl.biology.usgs.gov/DISCOVRE/gom.html

were produced summarizing the Lophelia II findings beginning with a final BOEM interim report in 2012 (Brooks et al. 2012) followed by the BOEM final report in 2016 (Brooks et al. 2016). Numerous blogs, mission essays, images, video clips and other information were also made available from expedition webpages for each cruise in 2008, 2009, 2010 and 2012 on the NOAA Ocean Explorer website. The USGS final report is in revision (Demopoulos et al. in revision) but other publications were completed (e.g., Morrison et al. 2011; Prouty et al. 2016).

II.1.ii – Other Deep-Sea Expeditions in the GoM since 2007

In addition to the Lophelia II studies, several other deep coral explorations have taken place in the Gulf since 2007 (Table 1). The *Johnson-Sea-Link II* manned submersible supported the Florida Shelf Edge Expedition (FloSEE) in 2010 and followed up one year later aboard NOAA ship *Nancy Foster* in 2011 deploying the *Kraken II* ROV. The R/V *Seward Johnson* and *Johnson-Sea-Link II* submersible concluded its legacy in the GoM in 2010. Harbor Branch Oceanographic Institute (HBOI) operated the vessel since 1985, but the vessel was sold in 2010. The NOAA ship *Okeanos Explorer* (2012 and 2014) and Ocean Exploration Trust's E/V *Nautilus* (2013, 2014 and 2015) engaged in telepresence cruises that provided shore-based observers real-time remote access to images of deep coral habitats using fiber-optic ROV feeds from the GoM seafloor.

Two new research platforms had maiden dives to deep coral and sponge habitats in the GoM. The R/V *Falkor* (Schmidt Ocean Institute) conducted ROV dives during its Deep-Sea Coral Shakedown Expedition in August 2012, with subsequent cruises to the South Texas Banks (September 2012) and other previously explored sites (November 2012). The R/V *Falkor* and E/V *Nautilus* both supported deep coral investigations by the Ecosystem Impacts of Oil and Gas Inputs to the Gulf (ECOGIG) consortium funded through the Gulf of Mexico Research Initiative. The new *Alvin II* submersible (Woods Hole Oceanographic Institution) also conducted its first science dives in the GoM (March – June 2014, dives no. 4679-4737) on a science verification cruise focusing on deep-water seep habitats in the northwestern GoM and the Florida Escarpment as part of a project funded by the National Science Foundation (NSF).

II.1.iii –Highlights of Research Findings from the Continental Slope

Valuable new information has become available from the many field and experimental studies, including data on the survival and growth rate of *L. pertusa* (Brooke & Young 2009, Larcom et al. 2014, Lunden et al. 2014), the extreme longevity of black corals in the genus *Leiopathes* (Prouty et al. 2011) and gorgonian octocorals in the genus *Paramuricea* (Prouty et al. 2016), as well as the vulnerability of these corals to pollution and disturbance (Hsing et al. 2013, DeLeo et al. 2016). The branching stony coral *L. pertusa* was found to grow in thickets on offshore energy platforms and shipwrecks with linear extension rates of 1-2 cm/yr on average (Larcom et al. 2014). Large *Paramuricea* and *Leiopathes* colonies (> 1 m) between 300-1,500 m depth were found to reach ages of 660 years for *Paramuricea* and as old as 2,100 years for *Leiopathes* (Prouty et al. 2016). The growth rates of these corals may depend on their proximity to major nutrient resources like the Mississippi River (Prouty et al. 2011) or the Loop Current. Because these corals are heterotrophic suspension feeders, it is worth noting that resource availability is likely to vary on finer scales as well, for example on different sides of a mound or canyon feature which may also contribute to different growth rates.

A few long-term monitoring studies measured bottom currents over extended (one year) and short-term periods in the northern Gulf. Long-term studies showed maximum bottom currents peaked at only 22.6 cm/s at the 1,420 m GC852 site, but a substantial peak of 60 cm/s occurred at the shallower 440 m site at Viosca Knoll (VK826, Brooks et al. 2016). Average current speed at VK826 was 8 cm/s, but there were periodic shifts in the current from west to east, corresponding with a decrease in temperature and salinity (Mienis et al. 2012) that suggest two alternating water masses impinging on the reef. Sediment traps were deployed at VK826 as well, in order to identify and quantify the sources of nutrition to the suspension feeding benthic assemblage. Two food pathways to the *Lophelia* corals were identified from trap samples; sinking organic matter (phytodetritus) from the Mississippi River and vertically migrating zooplankton (Mienis et al. 2012).

Significant contributions were made regarding the associations and limits of temperature, salinity, dissolved oxygen and aragonite saturation states for *L. pertusa* at natural reefs (Davies et al. 2010, Davies & Guinotte 2011, Mienis et al. 2012, Lunden et al. 2013) and in aquaria (Brooks et al. 2012, Lunden et al. 2014, Brooks et al. 2016). The environmental conditions at natural reefs were similar to those recorded for *Lophelia* reefs in the eastern North Atlantic, though dissolved oxygen and density were lower in the GoM (Davies et al. 2010). Interestingly, the aragonite saturation state was found to be lower at sites where *L. pertusa* was present than at sites where it was absent, suggesting that this factor was likely not an exclusive control of *L. pertusa* presence in the deep GoM (Lunden et al. 2013). The thermal tolerance of *L. pertusa* was also investigated. Experimental studies suggest that a temperature threshold occurs near 12 °C (Brooks et al. 2016). These results will help scientists and managers to understand the effects of climate change on deep coral habitats now and in the future.

II.2. Continental Shelf Studies of Mesophotic Habitats

The mesophotic zone is a transition zone between shallow reefs in the photic zone and deep coral and sponge ecosystems in the aphotic zone. These habitats occur between 30 and about 130 m depths on the continental shelf (this report includes heterotrophic corals in this zone at depths ≥ 50 m under the broad term deep corals). Reefs occur on substrate related to salt domes fossil structures and other hard bottom features in the northern and eastern

GoM on the Florida Shelf. The total area of mesophotic seafloor habitat in the GoM is vast, estimated by Locker et al. (2010) to be 178,885 km^2 (between 30-100 m), an order of magnitude larger than that depth zone of the U.S. Caribbean or the main Hawaiian Islands, at 3,892 km^2 and 3,299 km^2, respectively. The GoM continental shelf is broad and slopes gently, allowing mesophotic ecosystems to occur further offshore than in other parts of U.S. waters. These reefs may be more isolated from nearshore effects, like fishing intensity and nutrient runoff (Locker et al. 2010).

Epicenters of new research in the GoM mesophotic zone since 2007 were in three primary regions: (1) the Northwestern GoM, including the Flower Garden Banks National Marine Sanctuary (FGBNMS) and the South Texas Banks off the coast of Texas, (2) the Pinnacle Trend in the northern Gulf off Louisiana, Alabama and Mississippi, and (3) Pulley Ridge in the southeastern Gulf off Florida. Research on these ecosystems since the late 1970s has focused on exploration of hard bottom banks and mounds elevated above surrounding soft-bottom substrate in order to understand the character and abundance of the associated biological communities. Manned submersibles (Bright & Rezak 1978, Reed et al. 2005, 2006) and ROVs (Gittings et al. 1992, Weaver et al. 2002, Schmahl & Hickerson 2006) were used to explore and characterize dozens of pinnacles, banks and mounds in the Gulf's mesophotic zone, and most were reported as good habitat for scleractinian, antipatharian, stylasterid and gorgonian corals.

The purchase of a Forum Energy Technologies Mohawk ROV by the National Marine Sanctuary Foundation (NMSF) in 2013 has increased the exploration and characterization capabilities of the region. This science class ROV is operated by the University of North Carolina at Wilmington, Undersea Vehicle Program through an NMSF agreement. The vehicle is depth rated to 600 m and currently outfitted for operations down to 365 m.

II.2.i – New Research in the Northwestern GoM

The FGBNMS has conducted biological surveys since 2001 on reefs and banks in the Northwestern GoM to document the occurrence of deep corals and sponges within and outside the Sanctuary. The FGBNMS and partners have conducted 17 ROV cruises to visit a total of 16 banks between 2007-2015. Octocoral and black corals are abundant and diverse components of the benthic assemblages explored by these ROV expeditions. Survey photos and videos since 2003 were analyzed as part of a doctoral dissertation on octocorals (Etnoyer 2009) and a master's thesis on mesophotic black corals (Nuttall 2013) at Texas A&M University. The deep coral assemblages of the nearby South Texas Banks were mapped, surveyed and explored as well (Rodriguez 2015). Additionally, Dr. Suzanne Fredericq from the University of Louisiana – Lafayette, is investigating algae populations on the Northwestern GoM reefs and banks, including comparisons of areas impacted by DWH (Felder et al. 2014). The information on the complexity of shelf-edge habitats from these

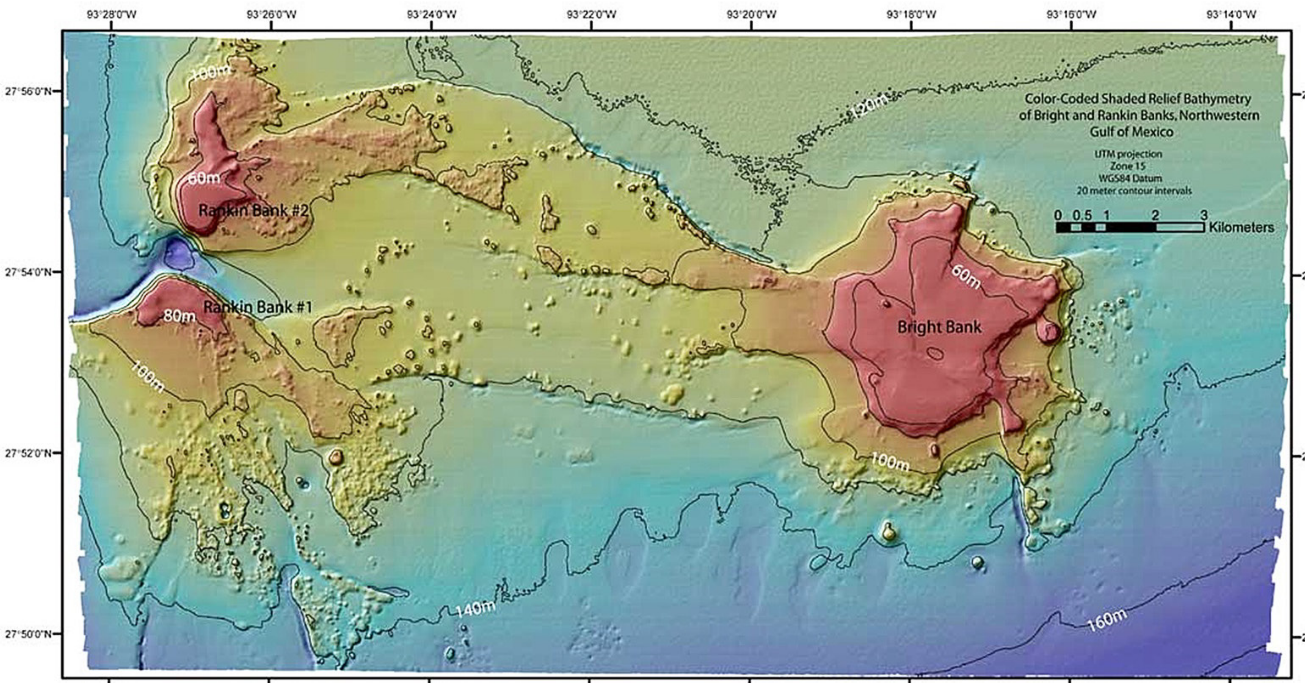

Figure 2. *High-resolution multibeam bathymetry map of the Bright and Rankin Banks showing complex topography and features. Red shaded areas represent BOEM no activity zones above a depth of 85 m. (Images courtesy of USGS, http://walrus.wr.usgs.gov/pacmaps/wg-index.html).*

surveys, and the imagery data obtained by FGBNMS and USGS, has helped to support management planning and development of proposed sanctuary expansion plans. The investigations described above and the multibeam surveys of numerous GoM topographic features published by Gardner et al. (1998, 2002) (Figure 2) prompted a broad new study awarded by BOEM in 2011. The purpose was to investigate the significance of features outside of existing BOEM environmental protection areas called No Activity Zones that prohibit all energy development activities. Figure 2 illustrates extensive numbers of features with significant relief revealed by multibeam data that lie outside No Activity Zones. This collaborative project began in 2011 in partnership with Louisiana Universities Marine Consortium, FGBNMS and the University of North Carolina at Wilmington Undersea Vehicle Program. The objective of this project was to survey outside No Activity Zones and inside core-biological zones to investigate habitat and species composition at these newly discovered bathymetric features (Sammarco et al. 2016). The first ROV cruises took place in October 2011, and continued through 2013 with two cruises in September 2012, two cruises in April 2013 and two cruises in June 2013 (see Table 1). Results of continued research will lead to more refined adaptive management and protective measures for these Potentially Sensitive Biological Features including the potential expansion of No Activity Zones.

In addition to the efforts by FGBNMS, NOAA's National Center for Coastal Ocean Science (NCCOS) conducted quantitative surveys in the mesophotic depth ranges of the Sanctuary. The project was titled "Fish and Benthic Communities of the FGBNMS: Science to Support Sanctuary Management" (Clark et al. 2014). The Cooperative Institute for Ocean Exploration, Research and Technology (CIOERT) also initiated investigations of hermatypic corals in the mesophotic depth ranges at the FGBNMS and Bright and McGrail Banks. In 2011, the NOAA ship *Nancy Foster* mapped Elvers Bank over an area of 30 km^2. Mapping has also taken place at Parker, Ewing, and Claypile Banks by FGBNMS and Texas A&M University. An online GIS-based mapping tool was developed to allow for virtual exploration of these deep-water habitats[3]. Catalogs of the major biological components are available through this portal.

The FGBNMS is actively pursuing an expansion plan that draws on these studies to support the incorporation of additional mesophotic reefs and banks in the northwest region. A draft environmental impact statement addressing sanctuary expansion was released on June 10, 2016, and presents a range of alternatives, including a preferred alternative recommending the addition of fifteen banks to the Sanctuary, which would increase the protected area from 56.21 miles^2 to 383.19 miles^2. This recommendation stemmed directly from the mapping, exploration and characterization activities in the region.

II.2.ii – New Research in the Pinnacle Trend Region

In the Northeastern GoM, mesophotic reef research has focused on the deep-water reefs of the Pinnacle Trend off Mississippi, Alabama and Louisiana (Alabama Alps, Roughtongue Reef and Yellowtail Reef) and on Coral Trees Reef and Madison Swanson Marine Reserve reefs south of the Florida panhandle. The Pinnacle Trend reefs were below the oil slick created by DWH spill for a period of several weeks (Figure 3). These surveys commenced in August 2010, three months after the spill, following a period of little research activity on deep corals and sponges in that area since 2003. New studies reported on the density, health and condition of gorgonian and black corals in relation to days below the oil slick, polyaromatic hydrocarbons (PAHs) in tissues and sediments, as well as fishing gear impacts (Silva et al. 2015, Etnoyer et al. 2016), in a 20-year retrospective analysis of ROV surveys.

II.2.iii – New Research in the GoM including Pulley Ridge

Research since 2007 in the Eastern GoM has focused on Pulley Ridge and Tortugas reefs, and shelf-edge habitats at Sticky Grounds, Madison-Swanson and Steamboat Lumps. These are true mesophotic reefs of zooxanthellate corals (*Leptoseris* and *Agaricia*) in deep-water to 90 m (Collier et al. 2015).

[3] http://www.ncddc.noaa.gov/website/google_maps/FGB/mapsFGB.htm

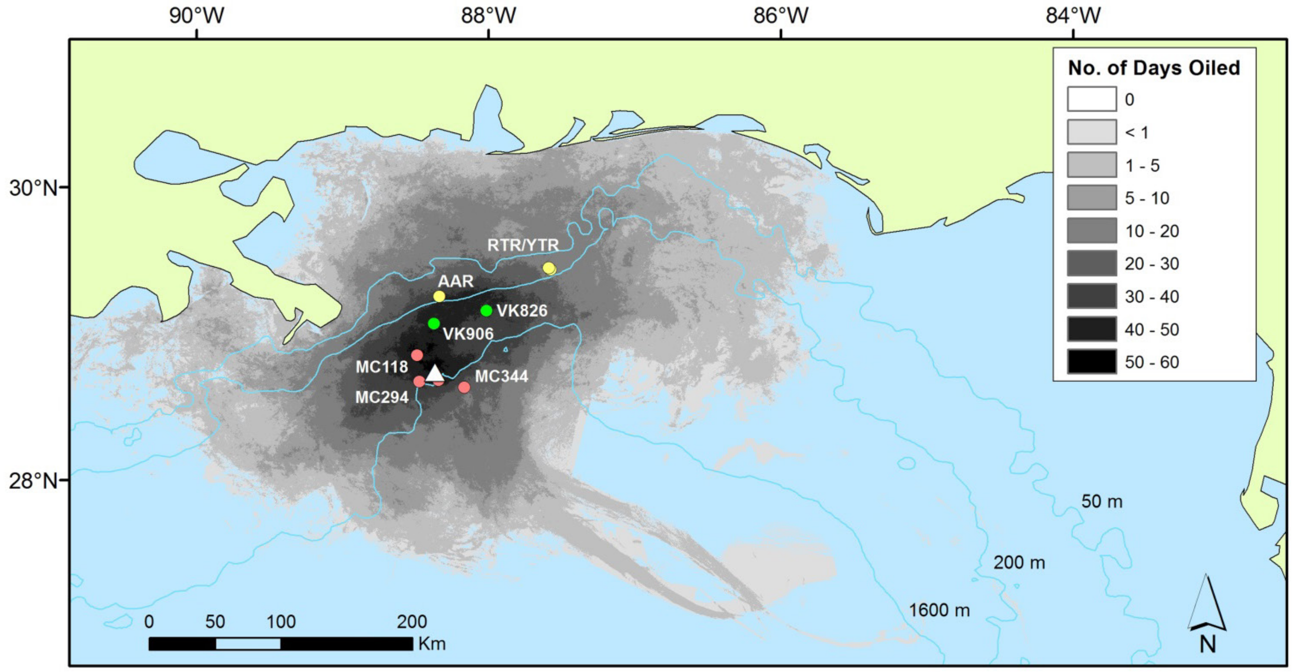

Figure 3. *Map showing known deep-sea coral aggregations (colored circles) in relation to the extent and duration of the surface oil slick produced by the* Deepwater Horizon *blowout at Macondo wellhead in lease block MC252 (white triangle). Yellow circles represent mesophotic reefs at Alabama Alps Reef (AAR), Yellowtail Reef (YTR) and Roughtongue Reef (RTR); green circles represent* Lophelia pertusa *reefs at Viosca Knoll; red circles represent deep gorgonian sites near Macondo wellhead (MC) at 850-1,850 m.*

Harbor Branch Oceanographic Institute at Florida Atlantic University (HBOI-FAU) led the Florida Shelf Edge Ecosystem (FloSEE) cruises in 2010 and 2011 under the auspices of CIOERT (Table 1). Results were detailed in reports by Reed and Rogers (2011), Reed and Farrington (2012), and Reed et al. (2012 a, b, c). One focus of the FloSEE work was in response to DWH, but the original intent of the effort was to characterize poorly known mesophotic and deep-water habitats on the West Florida Shelf using the *Mohawk* ROV, operated by UNCW-Undersea Vehicles Program.

Another project in the Eastern GoM mesophotic zone was titled "Connectivity of the Pulley Ridge – South Florida Coral Reef Ecosystem." Field expeditions took place in August 2012 and 2013 (Reed et al. 2014), sponsored by NOAA's NCCOS Center for Sponsored Coastal Ocean Research (CSCOR) and NOAA OER. The 5-year, $5 million project focused on population connectivity, specifically the role that mesophotic reefs may play in replenishing corals, fish and other organisms in downstream reefs of the Florida Keys and Dry Tortugas. The studies were primarily concerned with zooxanthellate corals and fishes in the mesophotic zone, but deep-water heterotrophic octocorals were documented as well (Table 1).

II.3. Research associated with the DWH Oil Spill

The DHW oil spill in April 2010 catalyzed a large number of assessment and research activities, including substantial new research on deep corals. The total volume of oil entering the GoM was approximately 651.85 million liters (172,200,000 gallons) after subtracting the volume of oil captured by various techniques (McNutt et al. 2011). This represents the second largest human-caused oil spill into the environment after the intentional 1991 Kuwait oil field destruction. During the DWH spill, the oil escaped at a depth of 1,500 m for a period of 100 days, and took the form of a submerged plume and an oil slick that was present on the sea surface and tracked by satellite for a period of several weeks (Figure 3). Deep corals were among the first benthic organisms targeted for assessment and linked to the DWH spill.

Damaged corals were discovered in lease block MC294, 11 km southwest of the Macondo well site (White et al. 2012). The area was identified as good potential for coral development by BOEM and NRDA investigators using industry 3D seismic seabed anomaly data, and discovered during the final dive of the previously scheduled Lophelia II field sampling cruise on November 2, 2010. The main area reported in White et al. (2012) measured 10 x 12 m, and about 43 gorgonian octocorals, primarily *Paramuricea biscaya*, were documented in this area or within 10 m.

Impacts to gorgonian live tissue were observed using high-definition video from the *Jason II* ROV, and a month later, from the manned submersible *Alvin*. Injuries were observed to 86% of the corals. Analysis of hopanoid petroleum biomarkers isolated from the brown floc on the damaged corals provided strong evidence that this material contained oil from the Macondo well (White et al. 2012). A calculation based on the age of the corals and the odds of the impact happening coincidently at this location and time (and not at any of the other 20 coral sites visited during that time period), yielded a probability of this being due to a different coincidental cause of about 0.001 (White et al. 2012). One follow-up study identified the anionic surfactant dioctyl sodium sulfosuccinate (DOSS), a component of the dispersant applied during the spill, in floc removed from one of the corals (White et al. 2014). Another recent laboratory study experimentally exposed deep-water corals (*Paramuricea* type B3, *Callogorgia delta* and *Leiopathes glaberrima*) to oil, the dispersant Corexit 9500A and mixtures of the two (Deleo et al. 2016). Under the conditions of this experiment the authors report the most severe declines in health were after exposure to dispersant alone and the oil-dispersant mixture. The mechanism of the impact from the spill was not determined, but White et al. (2012) suggested a possible link to the subsurface hydrocarbon plume that was detected by fluorescence and predicted from deep current models. The principal origins of the plume remain controversial and the divergent origins are discussed in most publications dealing with subsurface hydrocarbon dispersion (e.g. Hazen et. al. 2010, Camilli et al. 2010, Ryerson et al. 2012, Reddy et al. 2012). In a follow up study,

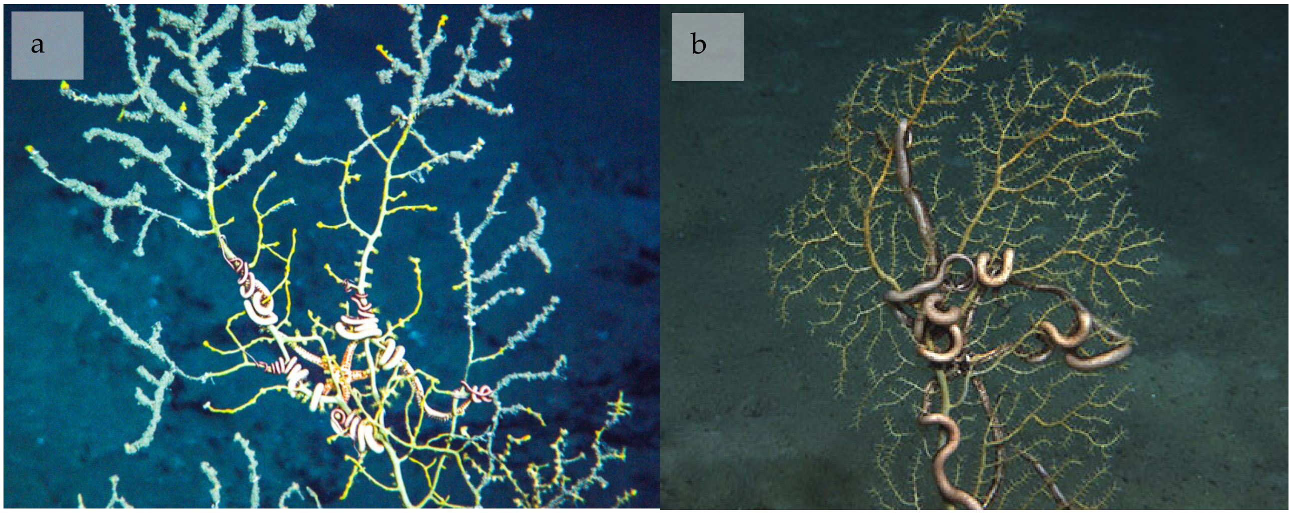

Figure 4. a) *Impacted* Paramuricea *sp. gorgonian with symbiotic brittle star* Asteroschema *sp. discovered in lease block MC294 at a depth of 1,370 m, 11 km southwest of the Macondo well site on November 2, 2010. Brown floc covering coral tissue contained hopanoid petroleum biomarkers consistent with oil from the Macondo well.* **b)** *Healthy* Paramuricea *sp. observed in October 2010 at a depth of 360 m over 450 km away from the spill site. (Images courtesy of Lophelia II, NOAA-OER/BOEM).*

Hsing et al. (2013) found that the median level of impact to coral colonies decreased over the next 17 months as some areas originally covered with floc appeared to recover. One of the impacted *Paramuricia* gorgonians discovered 6 km southeast of the Macondo well at a depth of 1,370 m is depicted in Figure 4 along with a healthy colony. Hydroid colonization occurred on some branches originally covered with the oil-containing floc and the probability of hydroid colonization was directly proportional to the original level of impact to the colony (Hsing et al. 2013). These authors emphasize the patchy nature of the impact on both the community and individual colony scale and suggest that the impacting agent may not have been evenly dispersed in the water at the time of impact.

Fisher et al. (2014a) reported the discovery of two additional coral sites impacted by the DWH spill. One community located 6 km from the Macondo wellhead (MC297) was heavily impacted, with 49 of 68 corals showing impact to over 5% of colonies in November 2011. Another site surveyed at that time, 22 km distant from the Macondo wellhead (MC344) and in much deeper water (1,850 m), was more lightly impacted with only 7 of 30 colonies showing some evidence of impact from the blowout. However, the depth of this site suggests that either the deep-water plume impacted the seafloor at greater depths than either models or the empirical evidence suggested, or that the impacting agent may have been oil or dispersant containing marine snow originating from the sea surface. Data on the oil content in sediment cores taken from these sites, as well as studies of the meiofauna and macrofauna present in the cores, are consistent with the coral data showing impacts to these sites resulting from the DWH blowout (Fisher et al. 2014b).

Additional studies conducted by NRDA focused on the health and condition of black corals and octocorals on mesophotic reeftop biotopes between 65-75 m depth, in relation to the number of days below the oil slick and evidence of exposure to PAHs. Pathologies in more than 400 octocoral and antipatharian corals were quantified using methods consistent with deep-water studies (Silva et al. 2015). The researchers found elevated PAHs in coral tissues and sediments, as well as demonstrable evidence of injury to corals located below the oil slick at higher frequencies than ever reported (Silva et al. 2015).

Another study with a Before-After-Control-Impact research design using video taken since 1985 showed a significant decline in octocoral health and condition at Alabama Alps Reef, Roughtongue Reef and Yellowtail Reef, positioned directly below the oil slick (Etnoyer et al. 2016). Less than 10% of colonies exhibited injury before the oil spill, while nearly 50% of colonies exhibited injury after the oil spill, with no significant corresponding change at reference sites (Etnoyer et al. 2016). Odds of encountering injury after the spill were up to 10 times higher compared to odds of encountering injured octocorals before the spill. Although proportions could not be determined, some injuries were attributed to visible interactions with fishing line or sedimentation, while others were attributed to the effects of surface oiling and dispersants (Silva et al. 2015, Etnoyer et al. 2016). These mesophotic studies extend the potential footprint of the DWH impacts to sites nearly 100 km distant from the wellhead.

The NRDA program, and subsequently the GoM Research Initiative, supported several years of research into mesophotic and deep coral habitats to document any potential injuries to coral associated with the spill. The principal cruises that contributed information to and subsequent work on these habitats are listed in Table 2.

II.4. New Information on the Distribution of Deep-Sea Corals

Research since 2007 has expanded knowledge that mesophotic reefs and deep coral habitats are widespread throughout the GoM (although generally restricted to relatively rare hard substrates). Maps showing the locations of deep-sea coral records in the GoM are presented in the Appendix. Several new large aggregations of corals and sponges were documented between depths of 50-2,000 m. New information has come to light showing changes with species assemblages on fine depth scales, over 10s of meters in the mesophotic zone and over 100s of meters in the deep-sea. There is also increased awareness about the mesophotic diversity of octocorals and black corals, which has been documented before (Rezak et al. 1986), but developed further using molecular techniques. Scleractinian corals have been shown to occur in zooxanthellate, azooxanthellate and apozooxanthellate forms, with the capacity to switch back and forth between forms (reviewed by Kahng et al. 2010).

Newly identified species in the GoM include *Oculina varicosa* aggregations near the Twin Ridges, south of Apalachicola, Florida (Barnette 2006) and a number of *Paragorgia* bubblegum corals when few, if any had been known from the Gulf before. In deeper waters (300-1,000 m), *L. pertusa*, *Leiopathes* spp. and *Madrepora* spp. have been found to be locally abundant. Primnoid octocorals (*Callogorgia* spp.) are also common in this depth range (Quattrini et al. 2013) and sometimes have catshark egg cases. Many new observations were made of *Paramuricea* octocorals, precious corals like *Corallium*, gold corals (family Chrysogorgiidae) and bamboo corals (family Isididae), which may occur in abundance as deep as 1,800 m or more (Doughty et al. 2014).

Habitat suitability models have added new insight to species distributions, and refined understanding of how depth and substrate have a significant influence on deep coral distributions (Davies et al. 2010, Kinlan et al. 2013, Georgian et al. 2014). New models of surface productivity, particle flux and bottom currents are available as well. One previously established pattern that is well reinforced is that large, structure-forming deep corals generally prefer hard bottom substrates with moderate to high relief. In the GoM, these substrates can take the form of banks and mounds, or authigenic carbonates near hydrocarbon seeps, or artificial substrates like shipwrecks, as well as oil and gas platforms. At the time of the last report (Brooke & Schroeder 2007), the wreck of oil tanker *Gulfpenn* was considered one of the largest aggregations of *L. pertusa* in the GoM (Church et al. 2007). Its sister ship, The *Gulfoil*, was discovered during Lophelia II in 2010 and this supported a similar luxuriant community of *L. pertusa* (Figure 5). Yet, research since that time has found even larger aggregations of *L. pertusa* in natural environments, including the largest *L. pertusa* reef known to date, called Robert's Reef.

II.5. Detection of Hard-Bottom Habitats using Seismic Anomalies

New coral habitats are being discovered routinely in the GoM, because new types of information are improving researchers' abilities to detect and predict deep coral habitat. With the continued refinement of industry-acquired 3D seismic seabed anomaly locations and new exploration (ground-truthing) of these anomalies using ROVs and autonomous underwater vehicles (AUVs), it is clear now that there are many thousands of additional habitats with high probability for the presence of corals. The total number of positive seismic reflectivity anomalies at the seabed (representing hard substrate within about 9 m of the seafloor) is now in the vicinity of 23,000 for the northern GoM (Figure 6). These discontinuous features range in size from hundreds of meters in diameter to many kilometers. However, it cannot be assumed that all of these seafloor anomalies correlate to coral and sponge communities or even that a hard substrate is exposed on the seabed. The presence of living

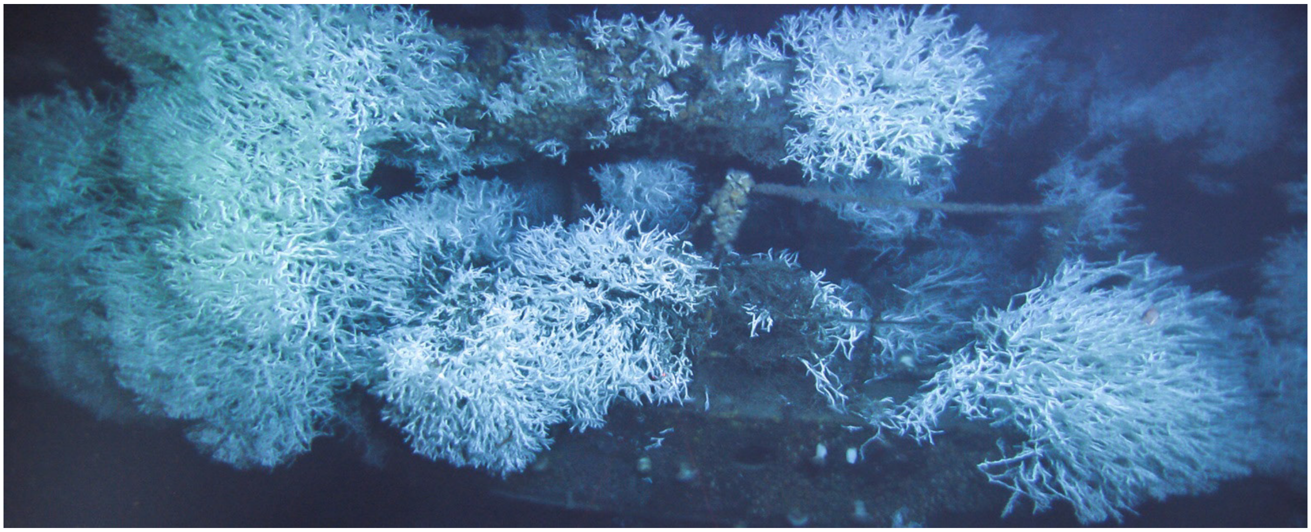

Figure 5. *Extensive* Lophelia *growth on shipwreck* Gulfoil *at 534 m. This ship sunk in 1942 resulting in 56 years of colonization when first surveyed in 2008. (Image courtesy of Lophelia II, NOAA-OER/BOEM).*

coral or dense hardground communities on seafloor anomalies needs verification with visual exploration. Less than 100 sites (less than 0.5% of total) have visual confirmation of exposed carbonate primarily colonized by deep corals (although the success rate of finding living coral habitats is very high as a proportion of selected anomaly targets). The seismic targeting process has been a foundational part of science expeditions for all the BOEM/NOAA/USGS studies between 2002-2012, including many sites chosen for the 2011 and 2012 NOAA *Okeanos Explorer* missions, and sites explored around the Macondo well during the NRDA effort (Fisher et al. 2014a).

II.5.i – Search for Lophelia Reefs using Seismic Anomalies

Seabed acoustic anomaly data has been relied upon heavily in recent years, directing numerous missions towards the location of deep coral habitat. One example can be illustrated through the story of a *Lophelia* location surveyed in 1955 by Moore and Bullis (1960). The position of the trawl catch with 300 pounds of *Lophelia* was reported to the nearest minute (29° 5′ N, 88° 19′ W), but there were no features in this area that could support any substantial *Lophelia* habitat. The depth of the collection in the publication correlates almost exactly with seabed 3D seismic anomaly data (and bathymetry) of a prominent feature located about 4 miles to the west of the discovery (or rediscovery) of lush *L. pertusa* sites at Viosca Knoll 906 (Schroeder 2007).

Seismic anomalies are publicly available on a website hosted by BOEM[4]. GIS shapefiles for more than 32,000 anomalies are now available.

[4]http://www.boem.gov/Oil-and-Gas-Energy-Program/Mapping-and-Data/Map-Gallery/Seismic-Water-Bottom-Anomalies-Map-Gallery.aspx

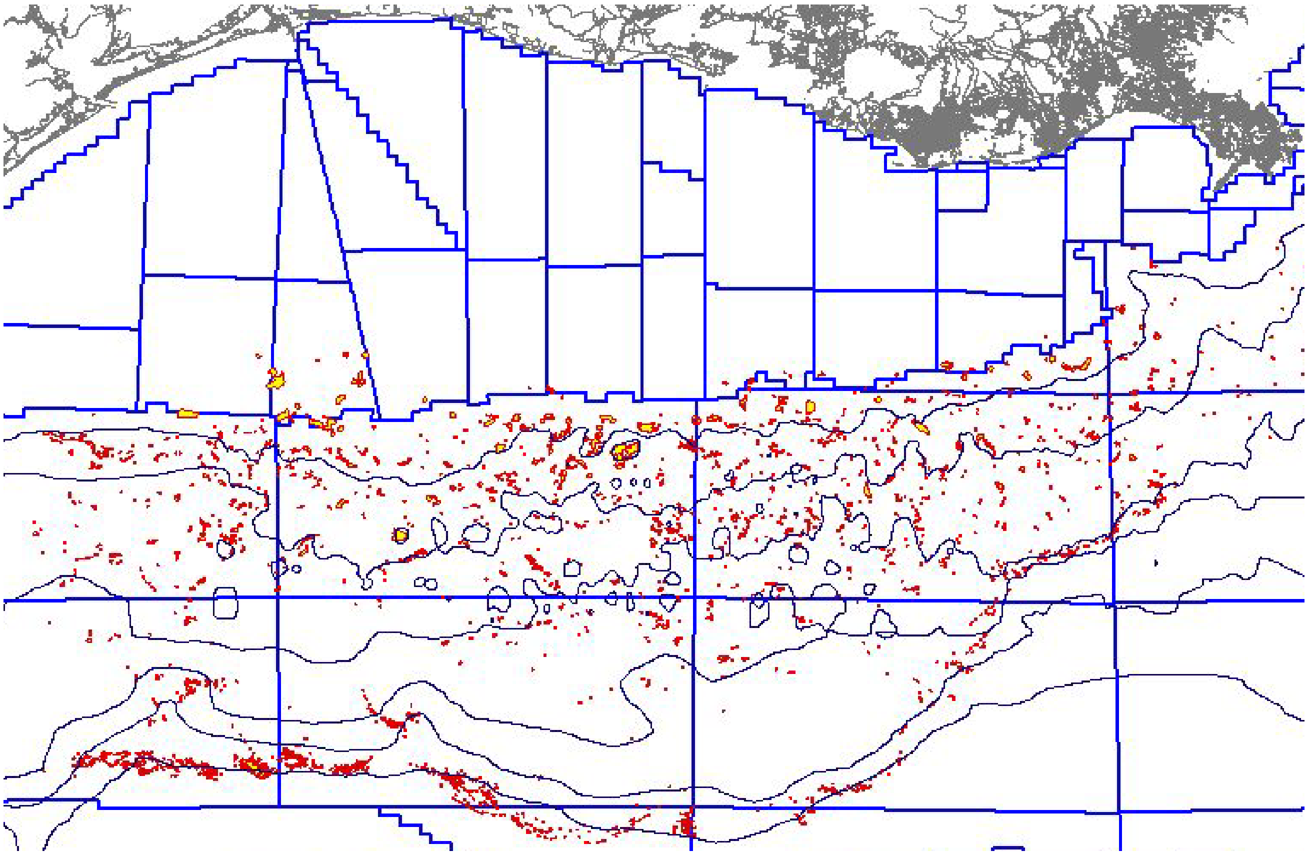

Figure 6. *Continental slope of the northern GoM with variety of seabed anomalies. The source 3D seismic data is extracted for the water bottom and can represent features up to 9 m below the surface. Red polygons represent interpretation and some consolidation of complex positive reflectivity features. Other features include pockmarks from gas expulsions and negative reflectivity (potential seeps). (Image courtesy of BOEM analysis of industry-acquired 3D seismic data).*

These data have been used to facilitate field explorations, as well as state-of-the-art habitat suitability models (Kinlan et al. 2013, Georgian et al. 2014). The most recent addition to the seismic anomaly collection is a new category for Cretaceous-aged platform-derived carbonate along the Florida Escarpment posted in 2012. One category includes talus detected on the lower Florida Escarpment. Future explorations off West Florida can access this information to guide their surveys.

One of the remarkable deep coral discoveries in the GoM since 2007 was a discovery in 2009 of a spectacular accumulation of *L. pertusa* and abundant black corals (*Leiopathes glaberrima*) at Robert's Reef. The location of the mound was associated with a negative seismic anomaly (Lunden et al. 2013), a short distance from earlier surveys in lease block VK862 and adjacent to the same large area of seabed anomalies associated with most of lease blocks VK862 and VK906. The Robert's Reef site showed that *L. pertusa* can form large mounds

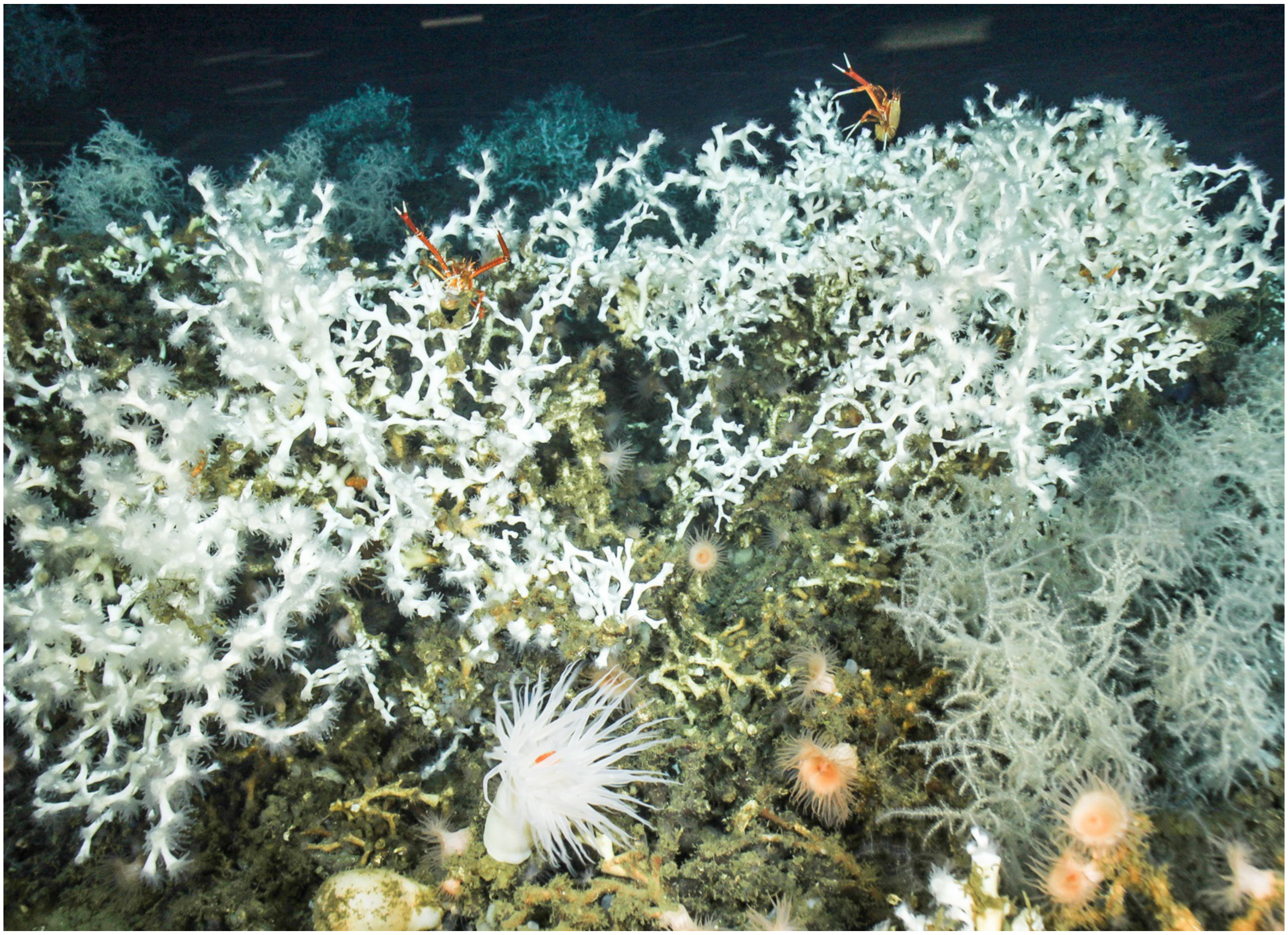

Figure 7. *Newly discovered expansive* Lophelia *community at Viosca Knoll lease block 906 (VK906) at a depth of 390 m. (Image courtesy of Lophelia II, NOAA-OER/BOEM).*

in the northern GoM (Figure 7), not just thickets of corals. Age-dating of piston cores from Robert's Reef reaching a depth of 16 m showed the presence of *Lophelia* coral throughout the core dated by a variety of methods to span approximately 300,000 years (Brooks et al. 2016). This is important because the smaller thickets known to researchers before 2009 suggested the Gulf may be suboptimal habitat for *L. pertusa* compared to the North Atlantic.

II.5.ii – Discovery of Madrepora Reefs from Seismic Anomalies

Another remarkable discovery since 2007 is that the branching stony coral *Madrepora oculata* is the dominant framework-forming scleractinian coral at depths below 800 m (Figure 8). This is in contrast to shallower depths where *M. oculata* occurs primarily as solitary colonies (Brooke & Schroeder 2007). In these deeper sites at GC852, *Madrepora* colonies were found at 1,410 m depth, in a framework with other structure-forming corals including *Enallopsammia profunda* and *Solenosmilia variabilis*.

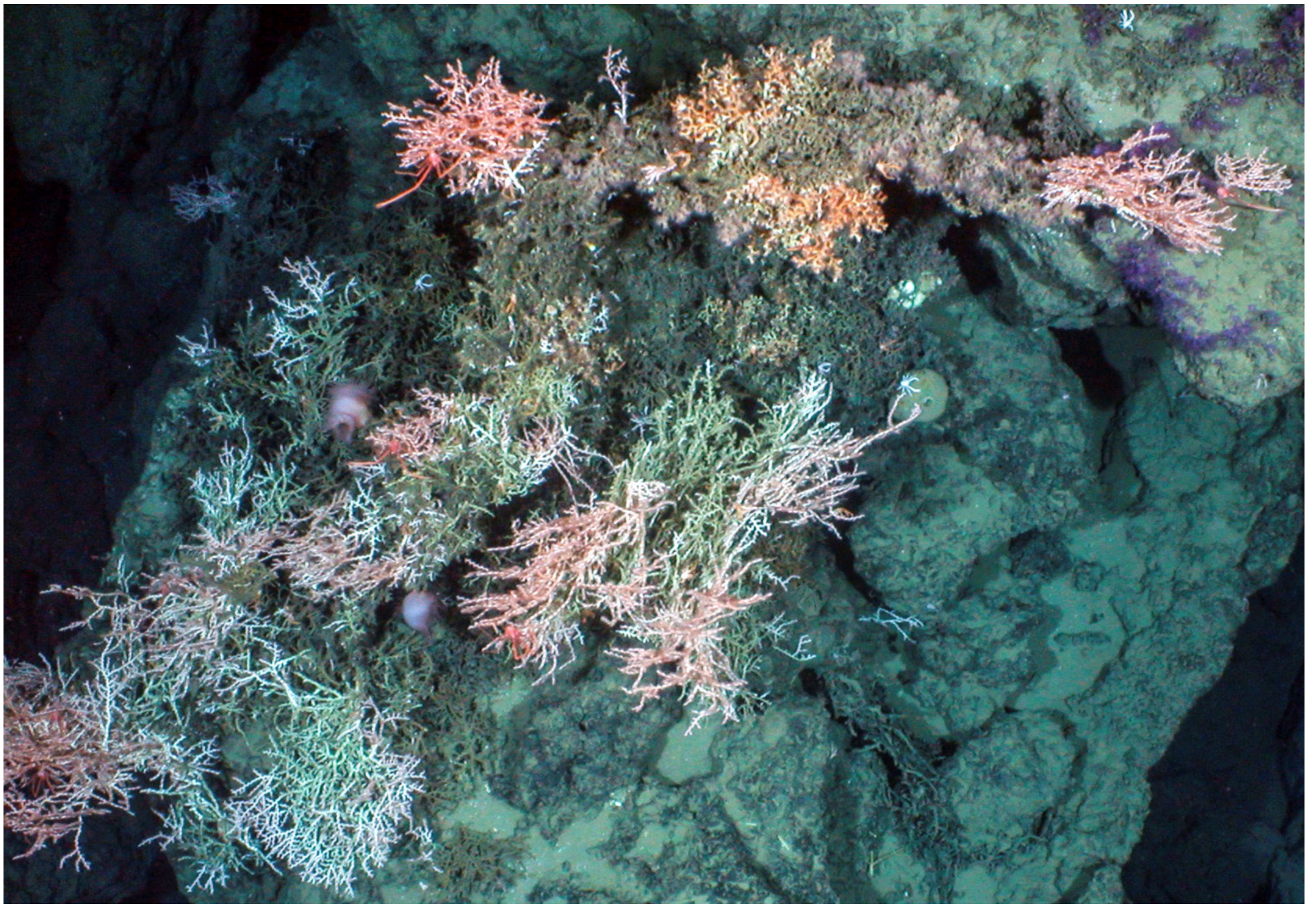

Figure 8. *Extensive* Madrepora oculata *with its pink and white skeleton, and other species of corals including* Enallopsammia rostrata *and* Solenosmilia variabilis *from the Green Canyon 852 site at a depth of 1,410 m. (Image courtesy of Chemo II, BOEM/NOAA-OER).*

A second *Madrepora* site occurs at a depth of 886 m in the Mississippi Canyon (lease block MC118). This site was explored during the Lophelia II project, and hosts numerous large thickets. A third site at 1,050 m depth in lease block AT357 hosts the largest deep-water coral assemblage currently known in the central GoM including *Madrepora oculata* (Figure 9) and thousands of colonies of large gorgonian octocorals *Paramuricea* sp. with numerous associated species of epifauna.

II.6. Artificial Hard-Bottom Substrates; Stepping-Stones for *Lophelia* corals?

New information since 2007 suggests that artificial substrates like shipwrecks and energy platforms for offshore oil and gas may represent important habitat and are potentially stepping-stones that connect populations of some deep corals (Brooks et al. 2016). To date, 533 structures are known from depths ≥ 50 m and 53 structures at depths ≥ 300 m. *L. pertusa* was first recognized on the deep-water

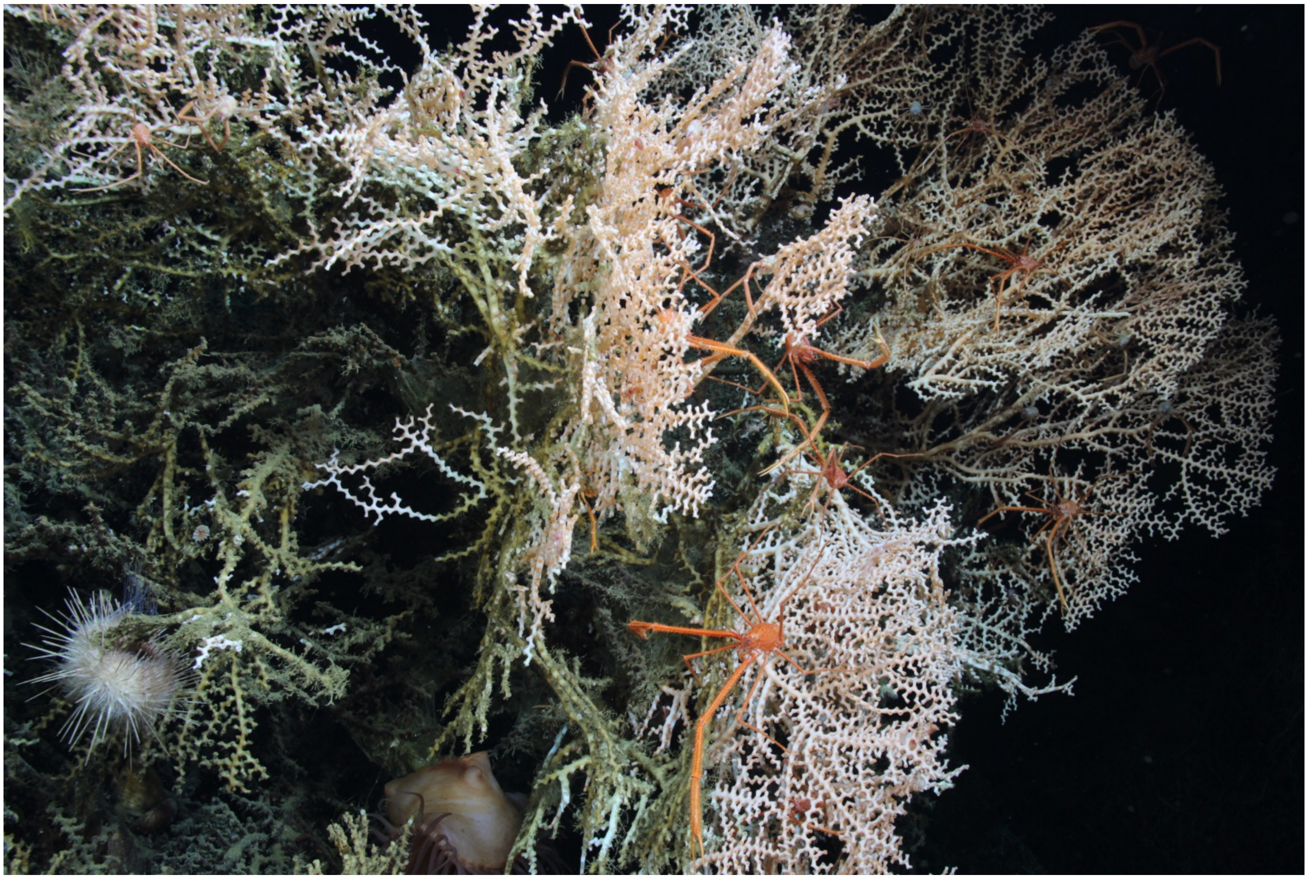

Figure 9. *Dense colony of* Madrepora oculata *with commensal squat lobsters at a depth of 1,050 m in Atwater Valley lease block 357 (AT357). (Image courtesy of Lophelia II, NOAA-OER/BOEM).*

Pompano platform at a depth of 400 m during a NOAA OER cruise in 2003[5] (Figure 10). The Lophelia II program subsequently found *L. pertusa* on three shipwrecks and all seven energy installations investigated (Brooks et al. 2016). Figure 11 is an example of a thriving *Lophelia* habitat that developed on a subsea manifold structure in lease block MC355 at a depth of 443 m from the installation date of 1991 to the time of observation in 2012. This study extended the known depth range for *L. pertusa* from 201 to 801 m depth, with the highest densities occurring near 500 m. Calculated growth rates on platforms were higher (≤ 3.2 cm/yr) than those measured using other methods at natural sites (Larcom et al. 2014). No large gorgonian or black corals were seen on the platforms, although large octocorals were present on some of the deeper and older shipwrecks investigated.

A total of seven wreck sites were investigated as part of Lophelia II. One site, the tanker *Gulfpenn* was once regarded as one of the largest aggregations of *L. pertusa* in the GoM

[5]http://oceanexplorer.noaa.gov/explorations/03bio/welcome.html

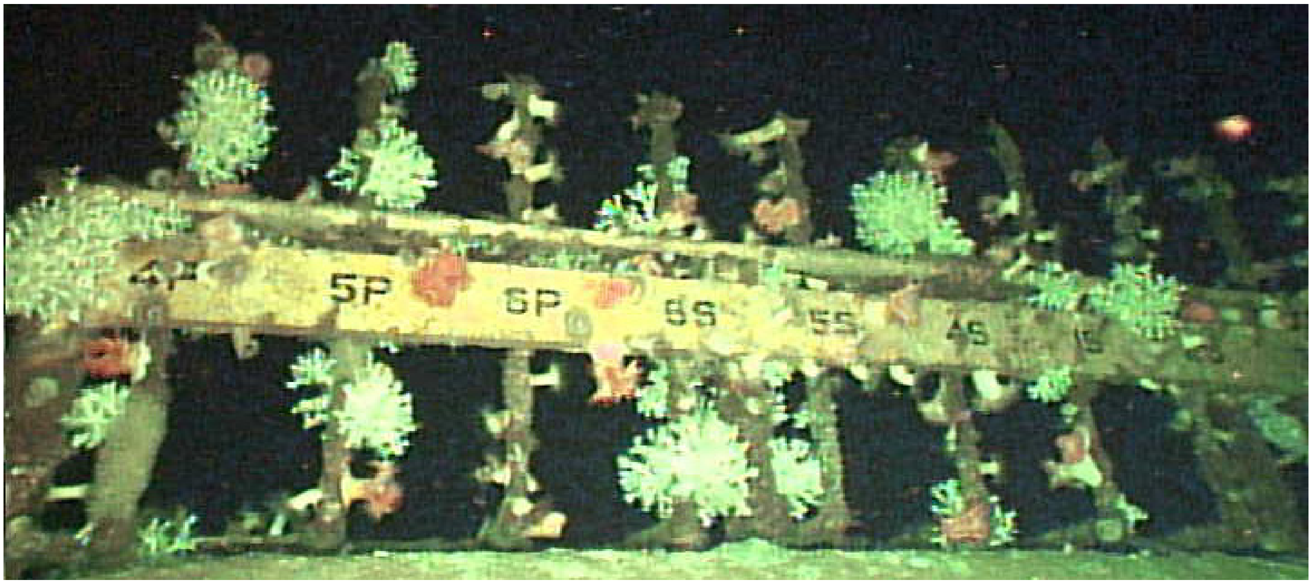

Figure 10. *Numerous colonies of* Lophelia *coral on portion of Pompano platform observed in 2003 representing maximum potential development of 9 years since installation in 1994. Depth approximately 305 m. (Image courtesy of John Reed, Harbor Branch Oceanographic Institute).*

(Church et al. 2007, Figure 12). The *Gulfpenn* survey was repeated from Church et al. (2007), but several new wrecks were documented in detail for the first time. Spectacular *Lophelia* coral communities were also discovered on the *Gulfoil* shipwreck, which were only distantly seen by Church et al. (2007), and another shipwreck that was named the *Ewing Bank* wreck.

II.7. Detection of *Lophelia* Reefs off Western Florida using Multibeam Data

A large extent of the west Florida shelf and slope has been mapped since 2007 using high-resolution multibeam echosounders aboard NOAA ships *Nancy Foster* (Naar 2010) and *Okeanos Explorer*[6], as well as the Schmidt Ocean Institute's R/V *Falkor*[7]. The German expedition on the R/V *Maria S. Merian* in 2012 also mapped the area. The new maps revealed hundreds of mounds and ridges, some of which were subsequently surveyed using submersibles and ROVs. Maps and data from these expeditions revealed a long continuous escarpment near 400 m depth, many mound features with 10 m relief or more, and a few isolated ridges with high vertical relief. Many features are within the *Lophelia* depth range (300-800 m).

The first reports of *Lophelia* aggregations on the west Florida slope were published by Reed et al. (2006) based on observations from the

[6] http://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/welcome.html

[7] http://www.schmidtocean.org/story/show/906

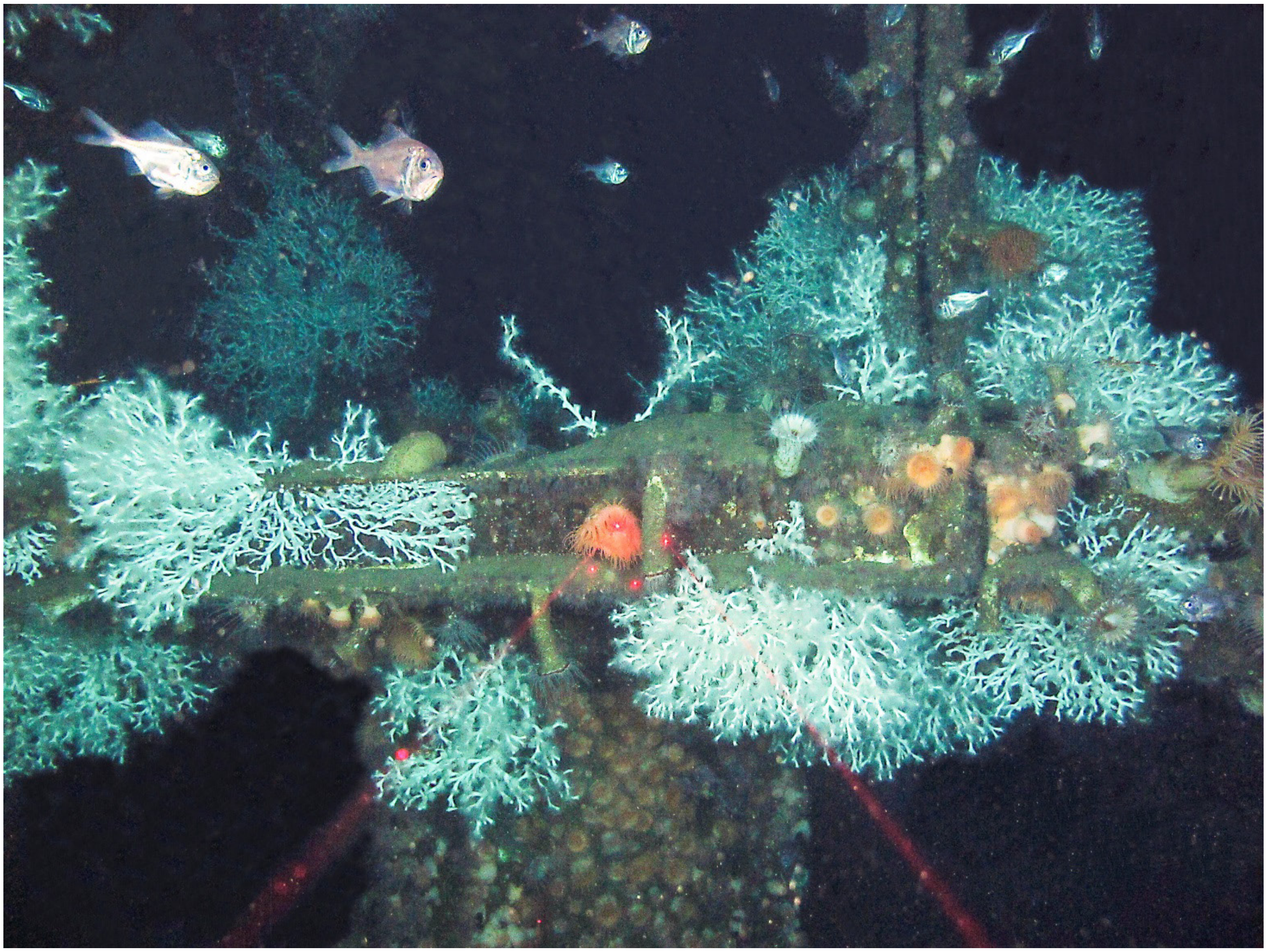

Figure 11. *Thriving* Lophelia *and other associated species on subsea manifold structure in lease block Mississippi Canyon 355 (MC355) at a depth of 443 m. (Image courtesy of Lophelia II, NOAA-OER/BOEM).*

Johnson Sea Link submersible. Extensive hard bottom ecosystems were documented on thewest Florida slope during several research cruises between 2008 and 2014. These included two European cruises that conducted seafloor mapping, water column profiling and documented *L. Pertusa* and other corals using underwater vehicles (Hübscher et al. 2010, Hebbeln et. al. 2012). Demopoulos et al. (in revision) describe the physical and oceanographic characteristics of these deep reefs and provide estimates of the accumulations from six cruises (2008-2012). The surveys identified mounds and ridges in < 525 m depths capped with living coral colonies, dominated *by L. pertusa*. A rocky scarp, running north-south for at least 229 km, supported lower abundances of scleractinian corals than the mounds and ridges, despite an abundance of settlement substrata. Several of these *Lophelia* aggregations were recommended for protection to the Gulf of Mexico Fishery Management Council (GMFMC) (Reed & Farrington 2014).

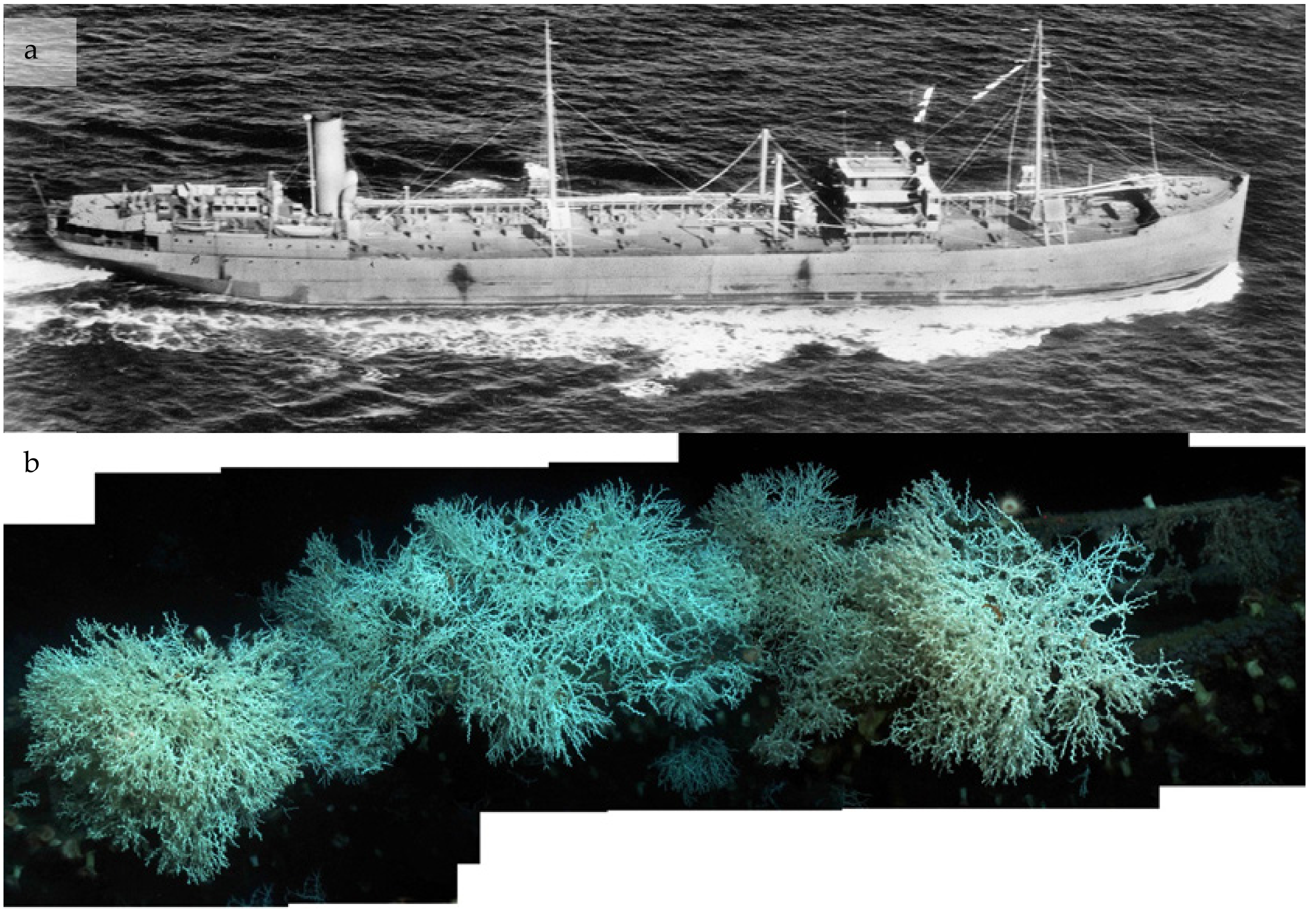

Figure 12. a) *The* Gulfpenn*, an oil tanker sunk by a German U-Boat in 1942 (Image courtesy of Mariner's Museum, Newport News, Virginia).* **b)** *Example of* Lophelia *coral development on the wreck. Photomosaic depicts numerous colonies nearly completely obscuring the upper bow with some ship structure visible in the upper right (Image courtesy of Lophelia II, NOAA-OER/BOEM and S. Lessard-Pilon).*

II.8. Advances in Understanding Population Connectivity

Although the advancing field of genetics applies to a wide spectrum of subjects related to deep corals, it fits well within the discussion of distribution. Recent advances have been largely due to the exponential growth in capabilities to perform genetic analyses. In the deep GoM, genetic techniques have been used to identify new coral species (Cairns et al., this volume) and provide estimates of population connectivity for the scleractinian coral *L. pertusa* (Morrison et al. 2011, Morrison et al. this volume), the black coral *Leiopathes glabberima* (Ruiz-Ramos et al. 2015) and the octocoral *Callogorgia delta* (Quattrini et al. 2015). Consideration of connectivity among coral habitats is fundamental to the understanding of basic ecology, and also critical for consideration of the sensitivity of populations with respect to anthropogenic impacts and potentials for recolonization. Predictions of larval dispersal for deep corals are difficult due to a lack of information on timing of reproduction, deep-water currents, larval longevity and behavior.

Research since 2007 has shown that *L. pertusa* occurs from the deep Garden Banks in the western Gulf to the deep Pulley Ridge in the eastern Gulf. Morrison et al. (2011) investigated the population genetics of North Atlantic and GoM *L pertusa*. That paper presented patterns of connectivity among *L. pertusa* populations at various scales and across a large portion of the species' Atlantic range from the GoM to Norway. Using a modeling approach, Morrison et al. (2011) found four distinct genetic groupings corresponding to ocean regions: GoM, coastal southeastern U.S., New England Seamounts, and eastern North Atlantic Ocean. In some regions, including the GoM, connectivity across larger geographic distances suggests that some larvae are broadly dispersed. Gene flow within the GoM indicates high connectivity. Thus, there is high potential for larvae to repopulate new areas following impact. However, Morrison et al. (2011) reported gene flow between ocean regions to be restricted, indicating more isolation and concluding that the most effective management approach for *L. pertusa* would include regional conservation networks. *L. pertusa* in the GoM were also evaluated for effects from manipulation, acidification, warming and deoxygenation with implications of population genetic variability being responsible for variable responses (Lunden et al. 2014). Additional information can be found in the connectivity spotlight article in this volume (Morrison et. al. this volume).

II.9. Distribution of Gorgonian and Black Coral Communities

Since 2007, black corals and gorgonians are increasingly recognized as key species within deep coral ecosystems that provide structure and habitat to other species, much like branching stony corals. A comprehensive study of species diversity across the entire GoM region was published by the Harte Research Institute in 2009 (Felder & Camp 2009), along with a public database curated by more than 140 taxonomic experts from 15 countries around the world, titled Biodiversity of the Gulf of Mexico. Data from this study indicates that the species richness of octocorals is comparable to scleractinian richness at all but the shallowest depth range (0-5 m) in the GoM (Figure 13). Another specimen-based study drawn from museum collections showed that octocoral diversity peaks at depths between 50 and 800 m depth (Etnoyer 2009, Figures 14 and 15). Depth gradients are evident, and highly correlated to oceanographic conditions, and they appear to contribute to patterns of biodiversity for deep corals in the GoM.

Other field studies since 2007 indicate that *Leiopathes* black corals, *Callogorgia* and *Paramuricea* octocorals are widespread in waters deeper than 200 m. *Antipathes*, *Cirrhipathes*, and *Tenacetipathes* are among the most commonly reported black corals from the mesophotic zone (50-200 m), whereas *Nicella*, *Ellisella*, *Hypnogorgia*, *Thesea*, *Scleracis*, *Bebryce*, *Swiftia* and *Placogorgia* are common gorgonian genera between 50-200 m (NOAA 2012).

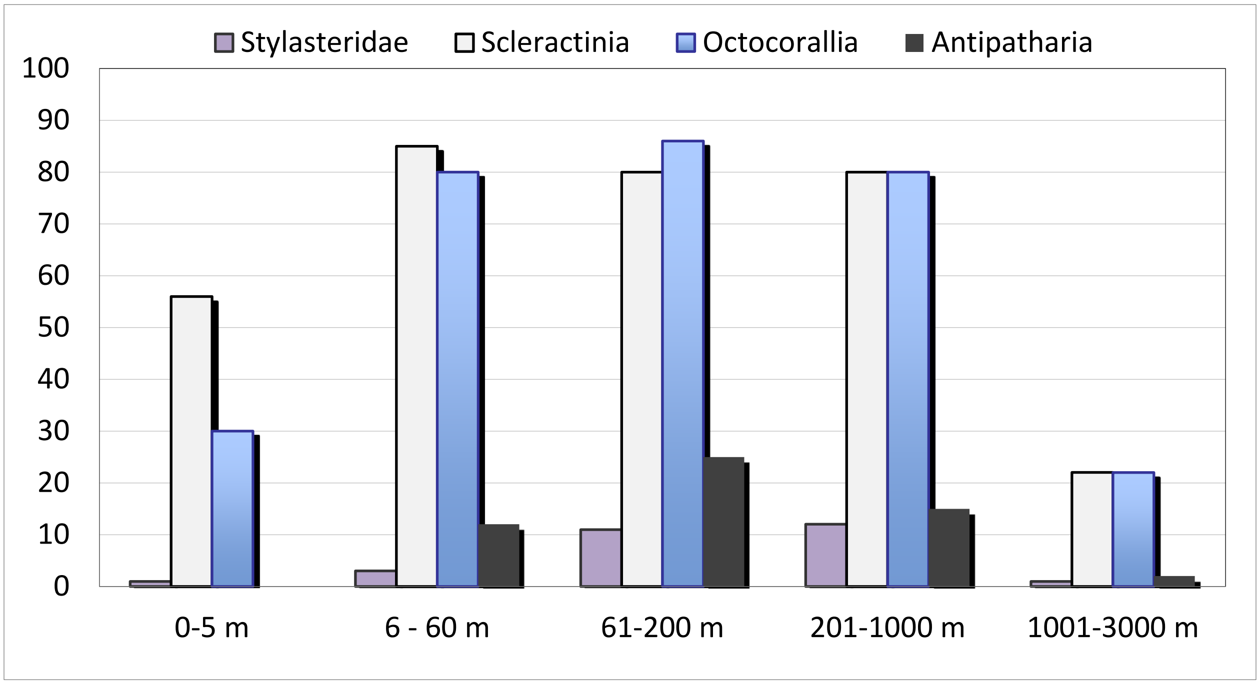

Figure 13. *Coral species richness by taxa and depth strata showing relatively high richness of deep-water taxa. (Graphic courtesy of Peter Etnoyer and Fabio Moretzsohn using the Biodiversity of the Gulf of Mexico database at the Harte Research Institute).*

These corals can occur in high densities, sometimes over large extents. Previous research has shown that both black corals and octocorals offer structure and refuge for demersal fishes in the mesophotic zone Weaver et al. 2002.

New information is available regarding the biogeography and vertical distribution of octocorals in the GoM. Etnoyer (2009) combined records from national and regional museums with field samples and cruise reports to identify hotspots of biodiversity. The study compared rates of species accumulation for octocorals in five depth zones: 0-50 m, 51-200 m, 201-800 m, 801-1600 m and 1600-3800 m. The highest rates of species accumulation were between 50-200 m and 200-800 m. Highest average diversity (Simpson's D) was in the 50-200 m depth range. The study identified some dissimilarity in the octocoral species assemblage between the northern GoM and the Florida platform (Etnoyer 2009). The findings contrast the hypothesis that deep coral assemblages are homogenous among the subregions of the Gulf.

A different study by Quattrini et al. (2014) based on samples collected during Lophelia II expeditions, supported the idea of two biogeographic regions in the GoM using measures of phylogenetic diversity, and extended this concept into deeper waters. Highest species richness for octocorals occurred at the shallowest sites (< 325 m) and the deepest sites surveyed (1,800-2,500 m). Specimens were

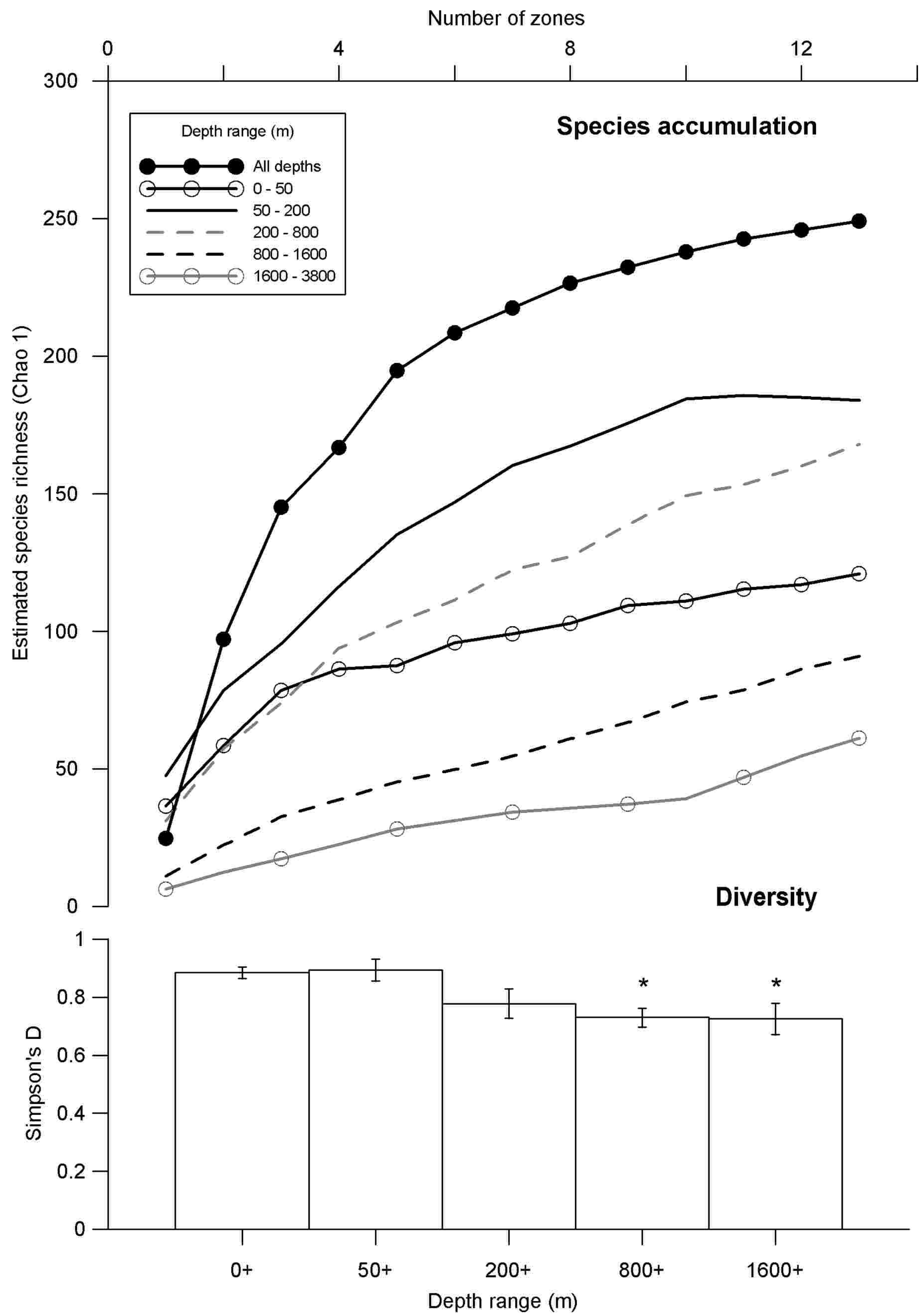

Figure 14. *Analysis of gorgonian species diversity by depth range from Gulf of Mexico museum collections showing high diversity in the 50-200 m depth range. The number of zones on the species accumulation curves correspond to regional zones defined in Etnoyer (2009). (Graphic reprinted from Etnoyer 2009).*

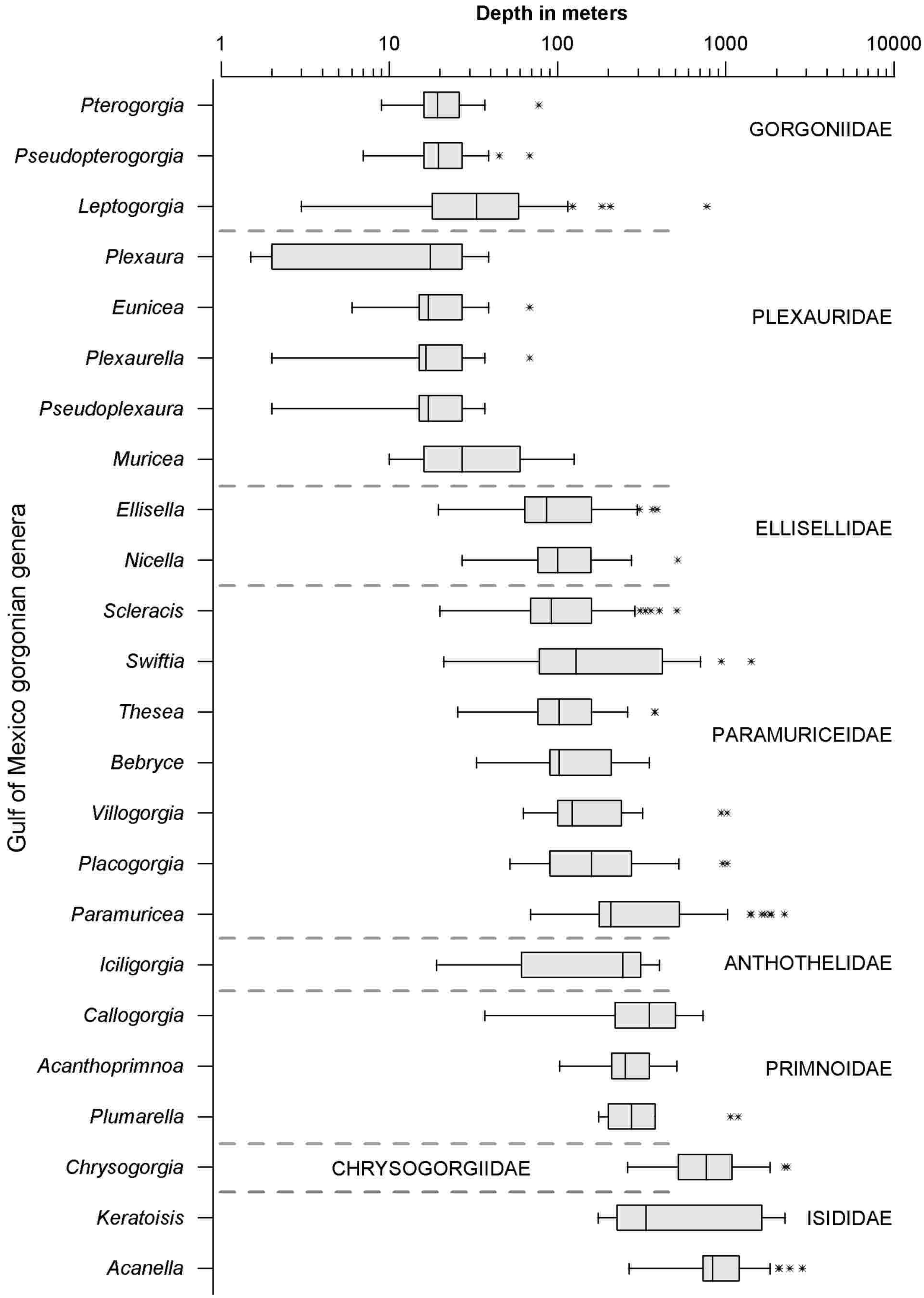

Figure 15. *Analysis of the vertical distribution of Gulf of Mexico gorgonian families and genera, as derived from museum collections. (Graphic reprinted from Etnoyer 2009).*

collected from 31 hard bottom sites in the northern and eastern GoM between 2008-2011. This pattern was different from that of the museum samples, and opposite of the typical pattern of deep-sea diversity in the GoM, which is expected to peak at mid-slope depths (Gallaway et al. 1988, Rowe & Kennicutt 2009). The research described transitions in octocoral assemblages at depth breaks near 325, 425, 600, 1,100 and 2,100 m. Octocoral assemblages on the west Florida slope represented a separate biogeographic group within the 425-600 m depth range compared to other groups located in the north central GoM. Using molecular tools, these authors also report on 12 species never before collected in the GoM, including three that are likely new to science.

Species within the genus *Callogorgia* are the most common and abundant gorgonian octocoral taxa reported from the upper continental slope (200-1,000 m) in the GoM (NOAA 2015). Quattrini et al. (2013) documented strong niche segregation with depth in the genus using specimen collections, video data, environmental niche modeling and DNA barcoding. *C. gracilis* occurred at the shallowest sites (depths up to 320 m), *C. americana* was found in mid-depths (339-384 m) and *C. delta* was found at the deepest depths (403-914 m) surveyed. *C. delta* was also associated with cold seeps, indicating that this species may have adaptations to living in areas of increased hydrocarbon seepage.

Following this study, Quattrini et al. (2015) examined whether depth could serve as an isolating factor in populations of *C. delta*. Significant genetic differentiation occurred across seven sites spanning 400 km of distance and 400 m of depth. Greater genetic differentiation was observed with vertical distance, rather than geographical distance; however, geographical distance may also play a role in limiting gene flow. The study concluded that water mass boundaries serve to isolate populations across depth, subsequently leading to adaptive divergence with depth (Quattrini et al. 2015). Another recent study examined the population structure of the black coral *L. glaberrima* in the deep Gulf (Ruiz-Ramos et al. 2015). These authors found that although different color morphotypes of this coral could not be distinguished genetically, they did show distinct differences in distribution. The study also found evidence of two distinct populations of *L. glaberrima*, one of which showed evidence of the ability for long range dispersal (and was present at all sites examined) and another which was restricted to VK826 and VK906 where it occurred sympatrically with the other lineage. These results indicate that coupled ecological and evolutionary processes are important in structuring the distribution of deep corals in the GoM.

Doughty et al. (2014) investigated the occurrence, density and size distributions of one of the most common gorgonian octocorals in the Gulf below 200 m (*Paramuricea* spp.). Similar to the results of Quattrini et al. (2015), the species of *Paramuricea* present in the GoM (based on molecular haplotypes) were partially segregated by depth. The authors concluded that as a result of their sparse distribution, low recruitment rates and slow growth rates, these deep-sea gorgonian octocorals are highly susceptible to anthropogenic threats.

NOAA's Deep Sea Coral Research and Technology Program (DSCRTP) has developed a national database of deep-sea corals and sponges with nearly 300,000 coral records including black corals and octocorals. This has greatly broadened the number of records of deep coral locations (see annex to this chapter). Habitat suitability models were developed from these occurrences to help fill gaps in the survey extent and to increase the reliability of predictions of coral locations that have never been surveyed before (Kinlan et al. 2013). Habitat suitability models have contributed immensely to a better understanding of the true extent of potential deep coral habitats at broad regional scales, as well as the mesoscale (Georgian et al. 2014).

II.10. Continental Shelf Mesophotic Habitats

II.10.i – Northwestern GoM

An updated biological habitat characterization scheme was released for the reefs and banks on the outer continental shelf of the northwestern GoM, including FGBNMS (Hickerson et al. 2008, Schmahl et al. 2008), based on the results of sampling efforts since 2003. Nuttall (2013) compared field identifications of black coral species (collected from the FGBNMS and other historical data) with laboratory identifications, and showed that species-level field identifications are not reliable and genus level identifications are more accurate. Nuttall (2013) also contains habitat suitability maps for antipatharians. Wicksten et al. (2014) described crustaceans associated with black corals, including a new species of crustacean, the squat lobster *Uroptychus marissae* (Baba & Wicksten 2015). Rodriguez (2015) studied black corals on nearby South Texas Banks showing highest abundance and diversity of black corals on the tops of banks compared to the flanks. An isolated observation of the antipatharian *Plumapathes pennacea* was reported by Boland and Sammarco (2005) on the crest of the East Flower Garden Bank at a depth of 22 m. Opresko et al. (in press) provided a guide to the antipatharians of the FGBNMS, which is useful throughout the region.

On the Flower Garden Banks, octocorals are absent shallower than 50 m (Bright et al. 1984), but a total of 24 species were documented in 16 genera (Etnoyer 2009) in deeper waters (52-130 m). The octocoral assemblage was stratified by depth, with a shallow group (50-70 m) and a deeper group (70-125 m). Hotspots of octocoral species richness and abundance were identified at the base of East and West Flower Garden Banks. Furthermore, four different octocoral assemblages were recognized at among six banks within a similar depth range, including Flower Gardens. Thus, nearby features 20-40 km apart may have very different species composition. One surprising result of the study was a high diversity of octocorals on low relief hard-bottom habitats between East and West Flower Garden Banks, on a feature now referred to as Horseshoe Bank.

The publications resulting from BOEMs Potentially Sensitive Biological Features investigations will provide insights into the distribution, diversity, dominance and structure of the mesophotic communities in the region, as well as the fine-scale geomorphology of a set of 14 banks in the northern GoM (Sammarco et al. 2016). This will also contribute to our understanding of the relationship between the fine-scale geomorphology and species richness in these habitats at a variety of spatial scales (Sammarco et al. 2016). Considerable range extensions of fish populations have resulted from the investigations in this region. An effort is currently underway to organize and publicize this data.

II.10.ii – Pinnacle Trend Region

Considerable new research occurred since 2010 on the mesophotic reefs at Alabama Alps, Roughtongue, and Yellowtail in the Pinnacle Trend region off Louisiana, Alabama and Mississippi (Figure 3), as well as on Coral Trees Reefs and Madison Swanson Marine Reserve off Florida. These studies also found differences in species composition between the two groups of reefs at similar depths (Etnoyer et al. 2016). Pinnacle Trend sites were dominated by the octocorals *Swiftia* sp., *Thesea nivea* and *Hypnogorgia* sp., while at the Florida sites, *Thesea rubra* and *Placogorgia* sp. were most common. These differences in species composition are consistent with the idea of a biogeographic boundary for deep corals between the northwestern and the eastern GoM. Differences could be driven by differences in seasonal temperatures, salinity, productivity or underlying substrate. In contrast, habitat suitability models developed for *Swiftia*, *Thesea* and *Hypnogorgia* indicate that these taxa are broadly distributed (Kinlan et al. 2013), but models can widen distributions beyond direct observations and rely on ground-truthing. Much remains to be explored in terms of population connectivity and environmental tolerances for the mesophotic sea fans and black corals.

II.11. Species Range Extensions

Many species of habitat-forming deep corals were encountered in the GoM for the first time (Figure 16), or in exceptional abundance, since the last report in 2007. Bubblegum corals (Paragorgiidae) were thought to be rare in the GoM, but they have been sampled and observed numerous times since 2008, at depths ranging from 360-1,800 m depth, in both the northwestern and eastern parts of the Gulf (Brooks et al. 2016). Precious corals (Corallidae) and *Iridogorgia* spiral corals (Chrysogorgiidae) have also been observed. A list of species discovered during Lophelia II or Chemo III, but not included in Cairns and Bayer (2009) is shown in Table 3. A comprehensive list of deep coral species in the GoM is provided in an annex to this chapter. This annex is modified from Cairns and Bayer (2009) to include newspecies occurrences and range extensions since the original publication. Clearly, the more we explore, the more we discover and observe.

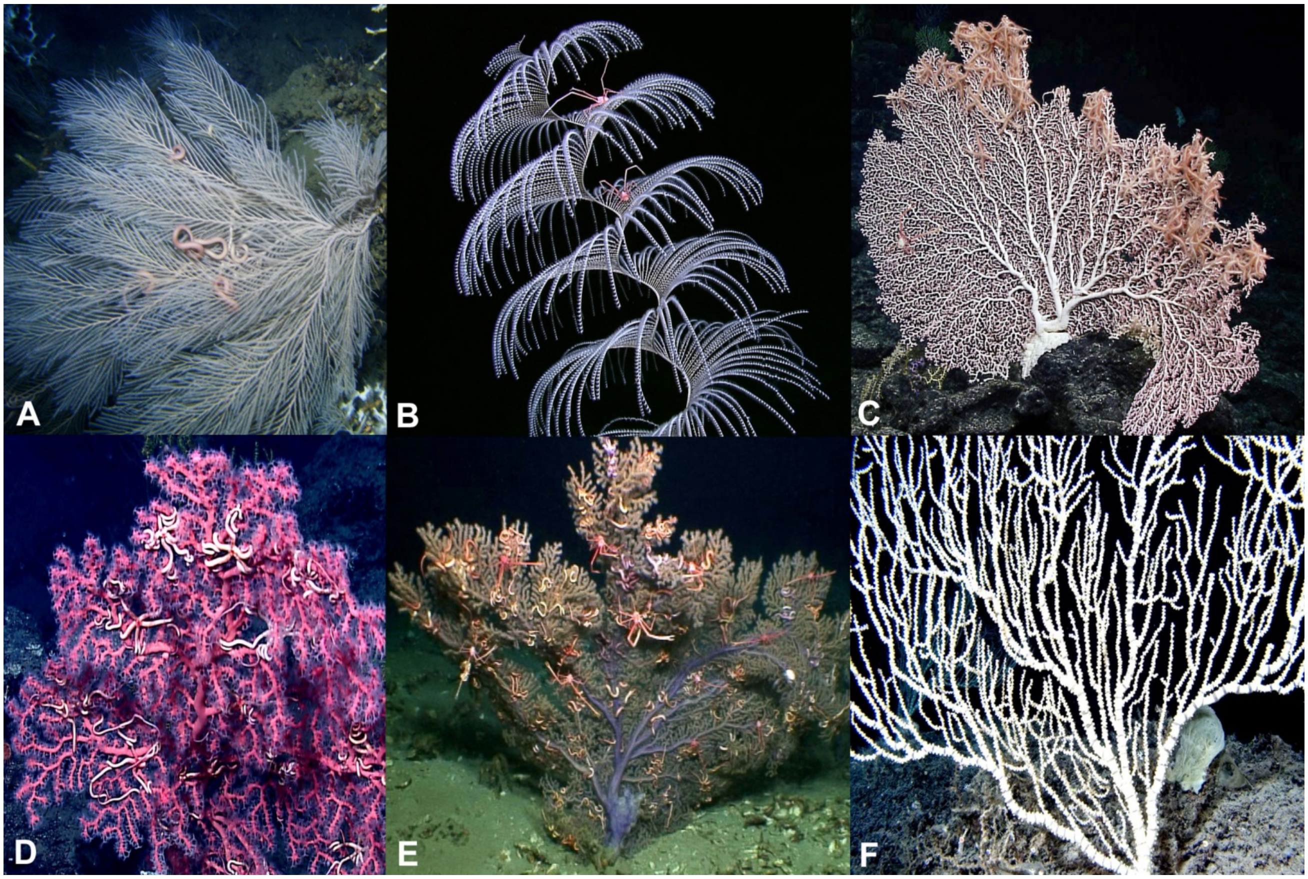

Figure 16. *Several species and genera of deep-sea gorgonian octocorals were recorded in the Gulf of Mexico for the first time since 2007, including species in the genera* **a)** Callogorgia, **b)** Iridogorgia, **c)** Corallium, **d)** Paragorgia, **e)** Paramuricea, *and* **f)** Keratoisis *(see annex list of deep-sea coral species).*

Table 3. *Octocoral range extensions documented from the* Chemo III *and* Lophelia II *study. (*Confirmed by taxonomic experts S. Herrera and J. Sanchez. Designations of new species await additional genetic data and morphological confirmation).*

Family	**Species**
Paragorgiidae	*Sibogorgia cauliflora*, Paragorgia wahine*, Paragorgia johnsoni, Paragorgia regalis*
Corallidae	*Hemicorallium niobe* (=*Corallium niobe*), *Corallium medea*
Primnoidae	*Callogorgia delta*
Chrysogorgiidae	*Iridogorgia splendens, Iridogorgia magnispiralis*
Plexauridae	*Paramuricea biscaya*
Clavulariidae	*Clavularia rudis*
Aquaumbridae	(new family described in 2012 from the tropical eastern Pacific)

II.12. Occurrence and Distribution of Deep-Sea Sponges

Limited data still exist on sponges in the deep GoM despite intense research over the last ten years. A map showing the locations of deep-sea sponge records in the GoM is presented in the Appendix. The paucity of research on these important taxa was identified but not fully addressed in the 2007 volume (Lumsden et al. 2007). Rützler et al. (2009) indicated the presence of 66 taxa for the deep-sea from 12 orders with three orders representing the majority of the total; Lithistida (15), Poecilosclerida (14) and Hexactinosida (12). No annotations or references in that summary are dated after 2004. The last comprehensive study of the deep GoM by Rowe and Kennicutt (2009) consisted of widely separated sampling stations ranging in depth from 200 to 3,750 m spanning across most of the northern GoM and also included some stations in Mexican waters. However, not much was reported on sponges and results were primarily qualitative.

A prior Gulf-wide study (Gallaway et al. 1988) was conducted in the mid-1980s and represents a more significant body of data on GoM deep-water sponges and also includes one of the few records of a high-density sponge area on the GoM slope. This study included 60 stations that spanned most of the northern GoM ranging in depth from 300 to 3,000 m. Gallaway et al. (1988) report 39 taxa of Porifera with 22 identified to species. Densities of small sponges from boxcore transects ranged from 0-137/m^2 with the maximum density observed at a single site at Station E5 during the fourth of five cruises at a depth of 2,902 m. However, the species observed were not reported (Gallaway et al. 1988). The ten most abundant taxa identified from boxcore samples as part of the macrofauna category, and mostly small in size and not structure forming, were only identified to genus or family. These included the genera *Stelletta*, *Sycon*, *Thenea*, *Stylocordyla*, *Thenea*, *Mycale* (species A and B) and *Microciona*, as well as the families Suberitidae and Suberotodae.

Sponges were also reported as part of the quantitative benthic photography component of Gallaway et al. (1988) using a drift camera maintained 2 m off the bottom at the same 60 stations. Hard bottom was not targeted. Densities from imagery exceeded densities from trawling at all stations. Maximum sponge density from imagery was 16,514 per hectare at one station at a depth of 1,400 m. Overall density of Porifera from benthic photography was approximately 450 individuals per hectare.

In the mesophotic region, research conducted by the FGBNMS has collected about 50 sponge samples in the 50-150 m depth range in the NW GoM. These samples were identified with the help of Dr. Christi Savarese, and Klaus Rützler at the Smithsonian National Museum of Natural History. An interesting glass sponge habitat was identified at Elvers Bank and warrants further investigation. Results from these efforts are available in poster form[8].

[8]http://flowergarden.noaa.gov/document_library/scidocs/spongeposter.pdf

II.13. New Information of Species Associations and the Role of Corals and Sponges as Habitat

Work has been done on deep coral associates including results from earlier studies (Lophelia I) ranging from microsymbionts to crustacea and fish. Wicksten et al. (2014) described crustaceans associated with black corals, as well as a new species of crustacean, the squat lobster *Uroptychus marissae* (Baba & Wicksten 2015). Giarad et al. (2016) reported on the benefits provided by the commensal ophiuroid *Asteroschema clavigerum* living on *Paramuricea* colonies impacted by the DWH spill. Recovery from visible impact and hydroid colonization of *Paramuricea* colonies was negatively correlated with distance from the ophiuroid. Branches within the area of influence of the ophiuroid were also more likely to recover, indicating likely benefits from its association with *A. clavigerum* through the physical action of ophiuroids removing material depositing on polyps. Cordes et al. (2008) reported 68 invertebrate taxa that were identified in close association with the *L. pertusa* coral framework in the northern GoM. Lessard-Pilon et al. (2010) report high diversity of fish and invertebrates in *L. pertusa* structure and that the highest diversity is associated with thickets containing high proportions of dead *L. pertusa*. Because *L. pertusa* in the central and northern GoM are often associated with current or historical seeps through colonization of derived carbonates, Becker et al. (2009) used stable isotopes to investigate a potential relation between *L. pertusa* communities and seep primary production. With the exception of a single gastropod (of 33 species tested), the authors found no evidence for a nutritional dependence of *L. pertusa*, or the fauna associated with the coral colonies, on seep primary production. Much of the work of the USGS Lophelia II team is contained in the regional publication list including Kellogg et al. (2009), Ross et al. (2012) and Demopoulos et al. (2010). Final reports from this suite of major studies also contain significant new information on deep coral associates, trophic relationships of associated species groups, substrate infauna and new results from microsymbiont studies.

II.14. New Research Priorities

Research priorities for deep coral in the GoM are many. There continues to be a need for baseline data in preparation for future catastrophic incidents and potential habitat impacts due to ecosystem impacts from climate change. The DWH incident clearly illustrates this need. Additionally, it is necesssary to understand long-term responses to major environmental events. Below we outline several research priorities to increase knowledge on deep-sea and mesophotic habitats in the region.

- Known deep coral and sponge sites need to be mapped at high resolution. This is the first step in exploration and characterization of these resources.

- Continued exploration and characterization of known sites in order to manage and protect resources.

• Long-term monitoring of deep coral habitats at a variety of sites throughout the GoM, including but not limited to, the sites impacted by the DWH incident.

• Growth rates, damage and aging of deep corals, as well as the natural abundances of fauna both directly and indirectly associated with deep corals.

• Enhance the predictive capability (i.e., use of remote sensing rather than visual detection) for identifying the distribution of deep coral including a modeling approach. NOAA's DSCRTP has begun a modeling project for the GoM. Additional ground-truthing and other research could be required. Ideally this would overlap with other research priorities.

• Understand two major components that determine the success of recolonization of potentially impacted habitats; 1) reproduction and development of species of concern (e.g., *Lophelia, Madrepora, Leiopathes* and *Paramuricea*) and 2) physical factors determining the transport of reproductive propogules of species of concern (both gametes and larvae).

• Investigations of genetic connectivity between populations are needed to effectively manage these resources.

• Archiving of invertebrate specimens including corals and related community species will continue with an ongoing contract between BOEM and the Smithsonian National Museum of Natural History. Additional scope of this program will include tissue archiving in their recently completed biorepository, as well as potential genetic barcoding. This effort should be expanded as much as possible and extended to other agencies involved in collection of deep-sea coral specimens.

II.15. Update on Management: New Information on Stressors

II.15.i – Oil and Gas Development

Brooke and Schroeder (2007) reviewed the stressors on deep coral communities in the northern GoM. Oil and gas development was identified as having a perceived medium level of threat to these communities – the highest relative threat level for human activities in the Gulf. As part of continued offshore development in the GoM, a total of 1,906 wells were drilled in water depths below 50 m from January 2007 to August 2015. Of that total, 1,066 were at depths below 300 m. Information on wells can be accessed through a variety of query options at a regularly updated internet site at BOEM[9]. Other than some visible linear physical impacts from anchor cables reported in Schroeder (2007), there have been no documented impacts to deep coral habitats from routine oil and gas activities.

The DWH oil spill and associated use of oil dispersants showed how a major accident could

[9] http://www.data.boem.gov/homepg/data_center/well/borehole/master.asp

affect deep coral communities. Numerous additional research publications directly involving deep corals and the associated communities will become available over the next few years as a direct result of research funded though federally required oil spill damage assessment, the GoM Research Initiative, as well as a spectrum of additional research funding related to the DWH event. One thing that is clear from NRDA benthic studies is that deep corals are important sentinel species that are useful for monitoring and vulnerable to oil pollution impacts.

II.15.ii – Fishing Threats

Bottom longlines for reef fish are a potential threat to corals and sponges in shelf-edge depths, because these fisheries target the same complex reef habitats where the target species of groupers and snapper occur including snowy grouper, Warsaw grouper and tilefish. Lost longline gear has been observed throughout the mesophotic reefs of the Northwestern GoM. Abandoned fishing lines have been observed with some frequency near Coral Trees Reef and Madison Swanson South Reef (MSSR), sometimes wrapped in and around gorgonian corals. The reefs are situated in an offshore region between Pensacola and Tampa, Florida known as the northern grounds for the GoM bottom longline fishery and the area of the Gulf where fishing for reef fish actually began in the 1800's (Prytherch 1983). Intense fishing pressure at MSMR led to closure in 2000, when the GMFMC prohibited all bottom contact gear in the reserve. Low levels of bottom longline fishing effort were reported from the Pinnacles region in 2001, but the majority of effort was concentrated in the eastern GoM, near Tampa, Florida (Scott-Denton et al. 2011). Observations of fishing line on Pinnacle Trend sites were few compared to Coral Trees Reef and MSSR (Etnoyer et al. 2016). Anchoring associated with specific types of fishing, such as bandit reel fishing, is also a threat to mesophotic reef systems.

There is little available information regarding new fisheries operating deeper than 300 m in the GoM that could significantly impact deep corals. An overview of this subject was a component of the Lophelia II project and is presented in Brooks et al. (2016). Commercial fishing pressures on deep coral in the GoM remain low compared to other regions; however, discarded fishing line has been documented in deep coral communities and may pose a threat to these coral communities (Fisher et al. 2014a). The only two fisheries identified as having some potential impact to deep-water scleractinian coral habitats, such as *Lophelia* and *Madrepora*, are limited to golden crab (*Chaceon fenneri*) and royal red shrimp (*Pleoticus robustus*). A fishery for the deep-sea golden crab has not developed since its early description in the literature (Brooks et al. 2016). However, this pot and trap fishery does come in contact with the bottom near 500 m depth where deep corals occur. The pots are strung together and retrieved by grappling hook before being dragged to the surface, so there is some potential for severe bottom disturbance in sensitive coral habitats. Golden crab is not currently a managed fishery in the GoM, but there is a small fleet operating off the southeastern U.S. coast.

There is some evidence of a golden crab fishery operating in and around *Lophelia* aggregations off the west coast of Florida. Golden crabs, a discarded crab pot, and broken *Lophelia* coral rubble were observed in 2012[10]. The feature has not been revisited since that time. There are only eight reports of golden crab landings in the NMFS fishery logbook databases from 1995 to 2004[11]. Landings data include small catches, some likely as by-catch, ranging from 25-641 MT over a period of eight years. The last reported data for golden crab landings in the GoM from the National Marine Fishery Service (NMFS) reference site for annual commercial fishery landings was 2004.

Royal red shrimp are fished in the GoM using bottom-contact trawling on the continental slope. The vessels target soft bottoms, but are occasionally close to known deep coral ecosystems including those in VK862/906. This species represents a small portion of the overall U.S. shrimp fishery (Stiles et al. 2007). The shrimp are sometimes observed close to and in association with deep corals (Ross 2005). Landings data from the last available NOAA data records for this species in 2014 is recorded for the Gulf States of Alabama (59.7 MT). A small catch was also reported in 2014 for the west coast of Florida (17.8 MT). The most recent data from Louisiana was in 2013 (2.8 MT). Texas reported relatively small royal red shrimp catches of less than 1 MT only in 2004 and 2012. Alabama landings diminished from 141 MT in 2009 to 102 MT in 2010, but rose to 159 MT in 2011 and 144 MT in 2012, remaining relatively consistent since the 1990s.

II.15.iii – Invasive Species

The invasion of the Indo-Pacific lionfish (*Pterois volitans* and *P. miles*) also poses a different kind of threat to GoM deep coral and sponge habitats. Lesser and Slattery (2011) report loss of biodiversity and resilience of nursery areas (mangroves), coral reefs, mesophotic ecosystems and artificial reefs, as well as cascading impacts across food webs. Based on the gut content analysis, and the size of potential prey, it should be acknowledged that the lionfish invasion poses a threat to prey in deep coral habitats, and this may have cascading effects throughout the lionfish depth range. One potential impact is that the reduction of herbivorous fish species abundance, indirectly impacts corals by fostering algal growth (Albins & Huxon 2013).

Invasive lionfish have been reported down to depths of 300 m (Albins & Hixon 2013). Lionfish were first captured off the northern Yucatan peninsula in December 2009 and in the northwestern GoM in September of 2010. Numbers of sightings have been increasing exponentially in the northern Gulf since 2011. Since lionfish were first observed in the FGBNMS in 2011, 2,614 lionfish sightings have been reported at depths ranging from 17-96 m,

[10] http://www.schmidtocean.org/story/show/915

[11] http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html

inclusive of both the shallow reef cap and mesophotic habitats through 2015. From this total, 1,484 (56.8%) have been removed. To date approximately 600 lionfish have been reported from other reefs and banks in the northern GoM, outside of the FGBNMS, primarily during ROV surveys at depths ranging between 50-177 m (Nuttall et al. 2014).

While lionfish were first observed by divers on all three banks of the FGBNMS in 2011, they were not recorded in long-term monitoring surveys until 2013, most likely due to the limited number of lionfish present during the first two years (Johnston et al. 2016a). Lionfish sightings from these surveys, occurring on the shallowest portion of the reef caps (17–27 m), varied among the three banks. In 2013, lionfish sighting frequency at East Flower Garden Bank was 25%, 33% at the West Flower Garden Bank and 5% at Stetson Bank. Sighting frequency in 2014 doubled at East Flower Garden Bank (50%) and increased at West Flower Garden Bank (40%), but decreased at Stetson Bank (2.9%). In 2015, sighting frequency decreased at East Flower Garden Bank (17%), increased at West Flower Garden Bank (60%), and was below 1% at Stetson Bank (Johnston et al. 2016 a, b). In 2015 long-term monitoring surveys, average lionfish density was 0.55 per 100 m^2 at the East and West Flower Garden Banks.

II.16. Management Actions

Much has happened in the GoM since 2007, particularly with regard to the management of the energy industry. Some new policies preceded the DWH oil spill, and it is likely that more management actions will result from ongoing reviews and research. Numerous reforms to the offshore oil and gas industry were also enacted in response to the DWH blowout and resulting oil spill in 2010.

II.16.i – Management of Oil and Gas Development

BOEM manages the exploration and development of the nation's offshore energy resources. Since 2007, the agency made changes to two specific regulatory policies for the oil and gas industry dealing with biological communities in the GoM, in addition to numerous changes in regulatory policies related to drilling safety.

BOEM supplements regulations that govern energy development operations on the Outer Continental Shelf through a regulatory mechanism called Notices to Lessees (NTL[12]). For example, NTL 2009-G40, titled Deepwater Benthic Communities, became effective in January 2010 and it increased the distance of avoidance from sensitive deep-water biological communities, including both chemosynthetic communities and deep coral habitats, for drilling discharges (610 m) and anchoring (152 m). This effectively doubled the distance of avoidance from prior NTL regulations. NTL 2009-G40 applies to all oil and gas activities,

[12]http://www.boem.gov/Notices-to-Lessees-and-Operators

including exploration and production drilling plans, as well as pipeline applications, in water deeper than 300 m (the depth was raised from 400 m to encompass newly discovered deep coral communities). As described in Schroeder (2007) there was some evidence of physical impacts to deep corals from anchoring activities in the past, specifically at the coral communities in lease block VK826. There have been no similar impacts observed to deep coral sites related to energy development activities on deep corals since 2002, with the exception of the DWH incident.

A second NTL (NTL 2009-G39, effective date January 2010), titled Biologically-Sensitive Underwater Features and Areas, applies to water depths shallower than 300 m and protection to sensitive biological features. In addition to previously established protective measures for topographic features and live bottom areas including the Pinnacle Trend region, a new avoidance category of bottom feature was created for this NTL. This new category, titled potentially sensitive biological features, is defined as features of moderate to high relief (about 2 m) that are not protected by other biological lease stipulations. This addressed the increasing awareness that extensive areas of exposed hard bottom and associated communities (including corals) were not included in No Activity Zone boundaries of named topographic features (e.g., Bright Bank, Geyer Bank and Sonnier Bank) or within the defined areas of high diversity features in the Pinnacle Trend. Although this major shift in protection for continental shelf features was first implemented in 2005 (part of earlier NTL 2004-G05), it was not addressed in Brooke and Schroeder (2007) and is continuing to evolve with extensive field research efforts in these habitat areas.

Comprehensive reforms and fundamental changes were made to offshore oil and gas regulation and oversight in response to the DWH explosion and resulting oil spill in the GoM to maintain responsible oil and gas drilling and production on the U.S. Outer Continental Shelf. Beyond the fundamental reorganization of the former regulatory agency, Minerals Management Service (MMS) into two new, independent bureaus – the Bureau of Safety and Environmental Enforcement (BSEE) and BOEM, numerous regulatory policies have also been enacted since 2010. With consideration of the impact to deep corals, the following new policies have a direct influence on the increased safety of deep-water drilling and future accident events. Other new policies such as more exacting inspection criteria and heightened standards for well design, casing and cementing are also indirectly tied to the issue but will not be detailed here.

1) One NTL was implemented shortly after the DWH spill, NTL 2010-N06 now updated to NTL 2015-N01, "Information Requirements for Exploration Plans, Development and Production Plans, and Development Operations Coordination Documents on the OCS" requires operators to demonstrate that they are prepared to deal with the potential for a blowout and worst-case discharge.

2) A drilling safety rule implemented in 2010 makes mandatory several requirements for the drilling process that enhance the safety of oil and gas drilling operations on the Outer Continental Shelf. It addresses both well bore integrity and well control equipment and procedures requiring two independent test barriers across each flow path during well completion activities. BSEE inspectors must now be on location and observe the Blow Out Preventer (BOP) testing prior to drilling commencing at the rig site.

3) Before receiving approval for deep-water operations, all operators now must demonstrate the capability to contain a subsea blowout like the one seen in the DWH spill. Operators demonstrate that they have access to all necessary equipment for subsea well control and containment, including a capping stack. As a result, there is now containment equipment available for industry deployment.

The most recent five-year leasing plan for GoM energy development (2017-2022) is described on the BOEM website. The five-year program consists of a schedule of oil and gas lease sales indicating the size, timing and location of proposed leasing activity that will best meet national energy needs for the five-year period following its approval. A total of ten separate lease sales have been proposed that will include the entire available GoM leases as opposed to separate sales for the Central, Western and Eastern Planning areas. The total submerged lands incorporated in the next five-year cycle include an area of approximately 647,499 km^2 (160 million acres).

Potential future management actions include the consideration of expanded No Activity Zones for the more formal inclusion of densely spaced habitat features adjacent to existing banks (potentially sensitive biological features).

II.16.ii – Other Management Actions

In June, 2016, the FGBNMS released a draft environmental impact statement outlining a range of alternatives for boundary expansion, including five alternatives ranging from no action (current sanctuary area of 56.21 $miles^2$) to a comprehensive plan to protect known high value benthic habitats and cultural resources in the north-central GoM. A preferred alternative was identified, which proposes an expansion to 383.19 $miles^2$, and includes Horseshoe (between East and West Flower Garden Banks), MacNeil, Rankin, 28 Fathom, Bright, Geyer, Elvers, Sonnier, McGrail, Rezak, Sidner, Bryant, Bouma, Parker and Alderdice Banks. All of these banks harbor significant habitats that include deep corals and sponges. In addition to these proposed expansion sites, the document also proposes to amend the boundaries of the three banks currently in the sanctuary (East and West Flower Garden and Stetson), to better encompass and therefore protect the deep coral habitats. After a period of public scoping, a Final Environmental Impact Statement will be developed and likely released in 2018.

NOAA's NMFS and the GMFMC have authority over fisheries in federal waters of the GoM. There have been no major changes in federal fishing regulations affecting deep coral areas since essential fish habitat designations in 2006. In June 2015, the GMFMC considered recommendations from its coral advisory bodies to evaluate 47 sites for Habitat Areas of Particular Concern designations and to protect them from fishing gear impacts (DSCRTP 2016). These sites are distributed throughout the GoM from Texas to Florida, and all have confirmed presence of multiple deep-sea coral taxa including the South Texas Banks, shelf and slope sites in the northern GoM and west Florida Platform including sites in Mississippi Canyon, Green Canyon, Garden Banks, Pinnacle trend and Viosca Knoll. The GMFMC plans to seek input from the fishing community on this proposal before officially starting a process to amend the Fishery Management Plan for Coral and Coral Reefs with new Habitat Areas of Particular Concern designations.

II.17. New Management Priorities

Following on from the ongoing Potentially Sensitive Biological Features shelf-edge study described above, additional high-resolution mapping will be needed for GoM topographic features where only low-resolution bathymetry is known (most from early 1970s). Additional mapping will lead to further investigations of any relevant benthic features and consideration of additional management protective measures. Results from this study will allow refinement of avoidance of energy development activities from benthic features occurring outside of No Activity Zones established by BOEM, as well as help guide development of other potential protective measures by other agencies.

If future oil and gas leasing moves farther east in the GoM, additional investigations on the west Florida shelf and slope will become a higher priority to inform management decisions for protective measures within this area that is much different than authigenic carbonate features of the rest of the GoM. Newly released BOEM shape files of water bottom seismic anomalies in this area will be very informative in the future, by allowing targeted research. Additionally, these files will be fundamental for management decision-making related to avoidance criteria of hard substrate depicted in survey databases.

III. Conclusion

An extensive amount of research on deep corals has been performed in the GoM since 2007, both prior to the DWH incident and afterwards, leading to increased awareness among managers and the public. This awareness has resulted in significant management actions to protect deep coral habitats in the mesophotic zone and deeper waters. Even though much less targeted research has been devoted to deep-water sponge ecosystems, it appears sponge communities (at least high-density communities) are relatively rare in the GoM compared to corals. The DWH incident was a landmark event with major revelations related to deep spill impacts including the unclear dynamics of deep plumes, extensive subsurface and surface dispersant use, the potential for impacts to deep-water habitats from horizontal transport of hydrocarbon plumes and from oiled marine snow. Increased understanding of genetic diversity, age, growth, reproduction and distribution of deep corals will greatly benefit management efforts, but much remains to be discovered and described. The availability and interpretation of GoM seismic reflectivity data have greatly facilitated discovery of new deep coral habitats throughout the northern GoM. The addition of more sophisticated modeling and ground-truthing efforts has greatly enhanced our understanding of deep coral distribution in the GoM. New multibeam data and exploration efforts along the West Florida Shelf has led to the subsequent discovery of large aggregations of sensitive coral habitats, and these should be investigated in the future to determine their extent and degree of vulnerability to climate change and other anthropogenic impacts. There continues to be a need to map, explore and characterize vast areas of the GoM and to better understand the biology and ecology of deep corals and sponges in order to provide the understanding necessary for the development of appropriate regulatory and protective measures.

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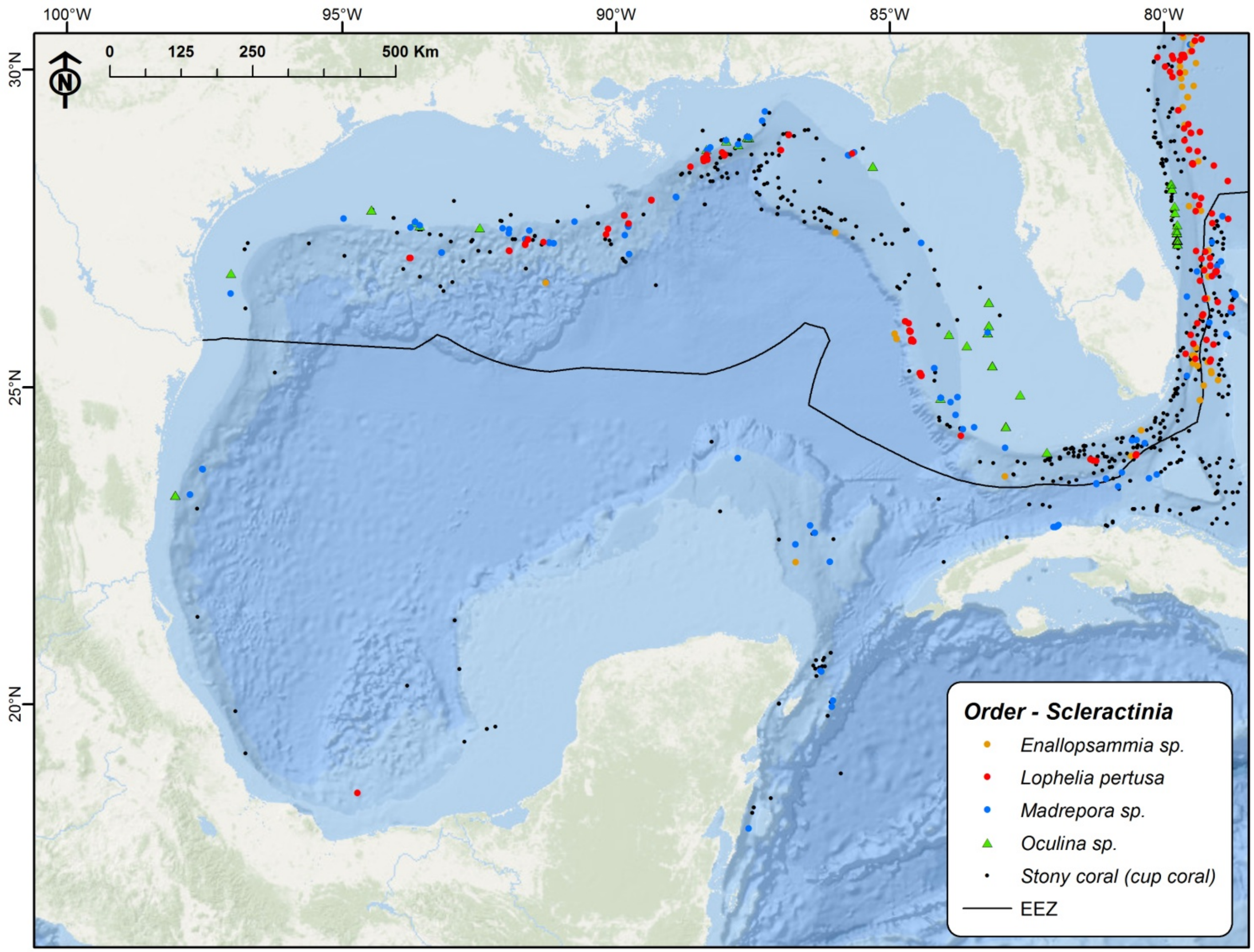
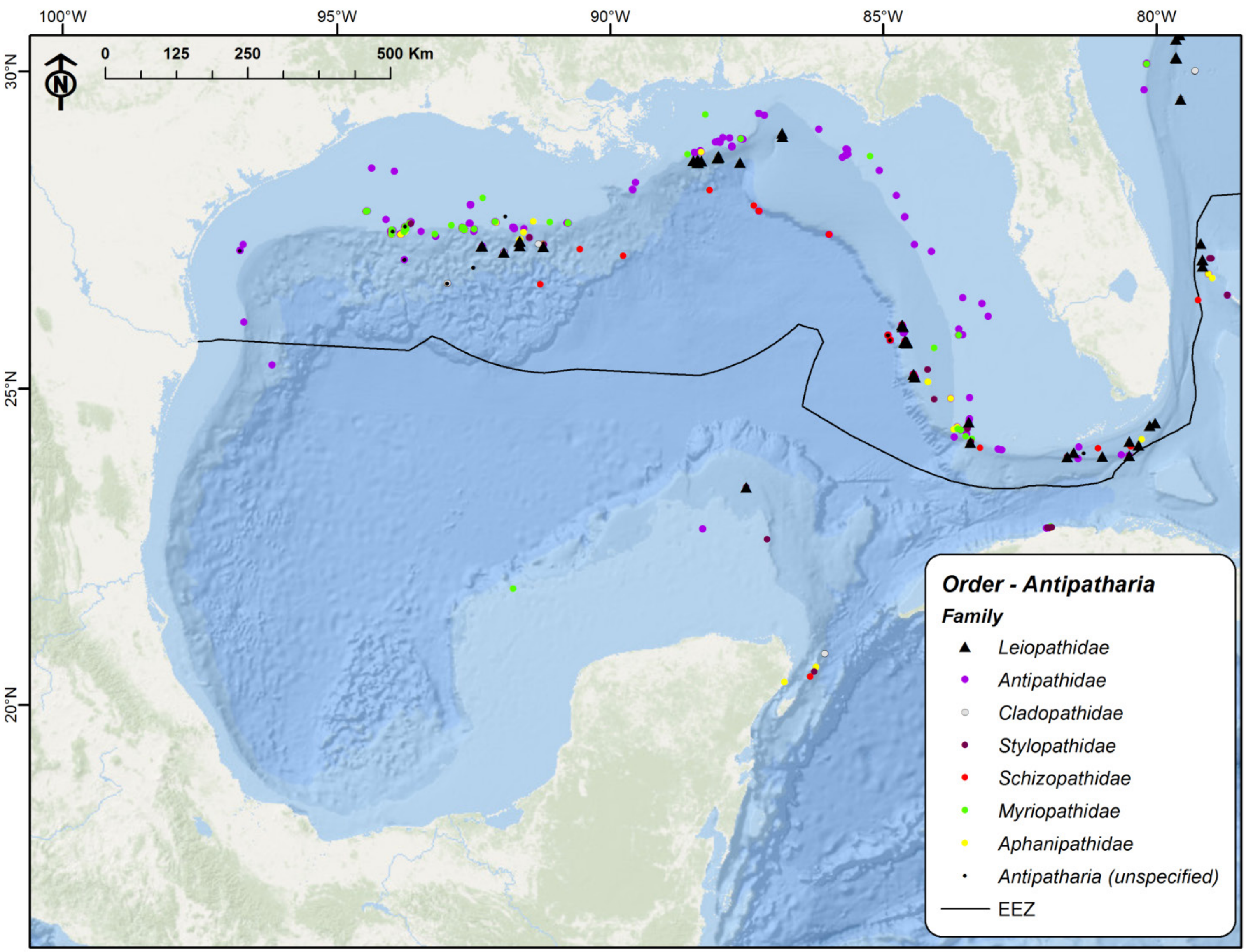
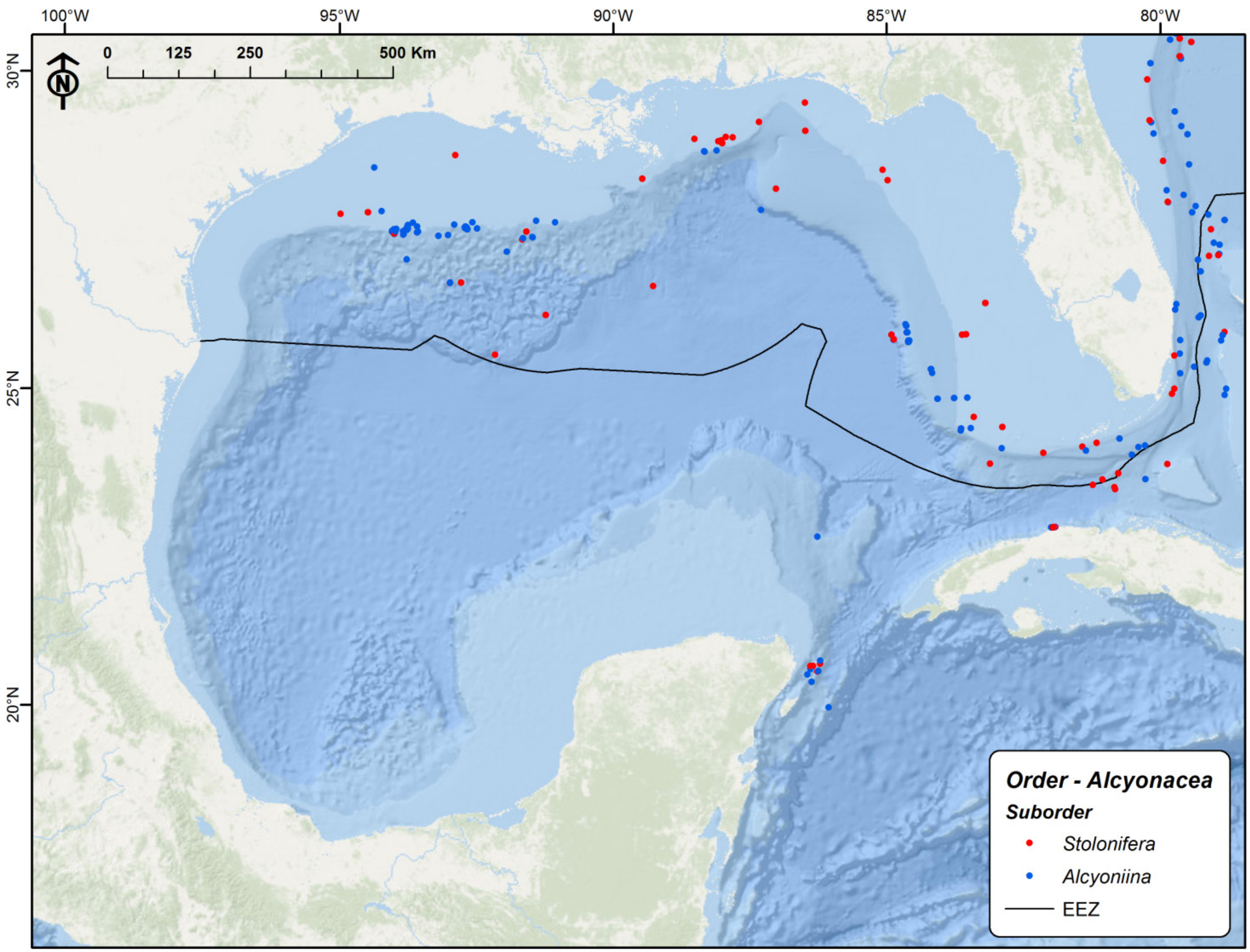
Appendix



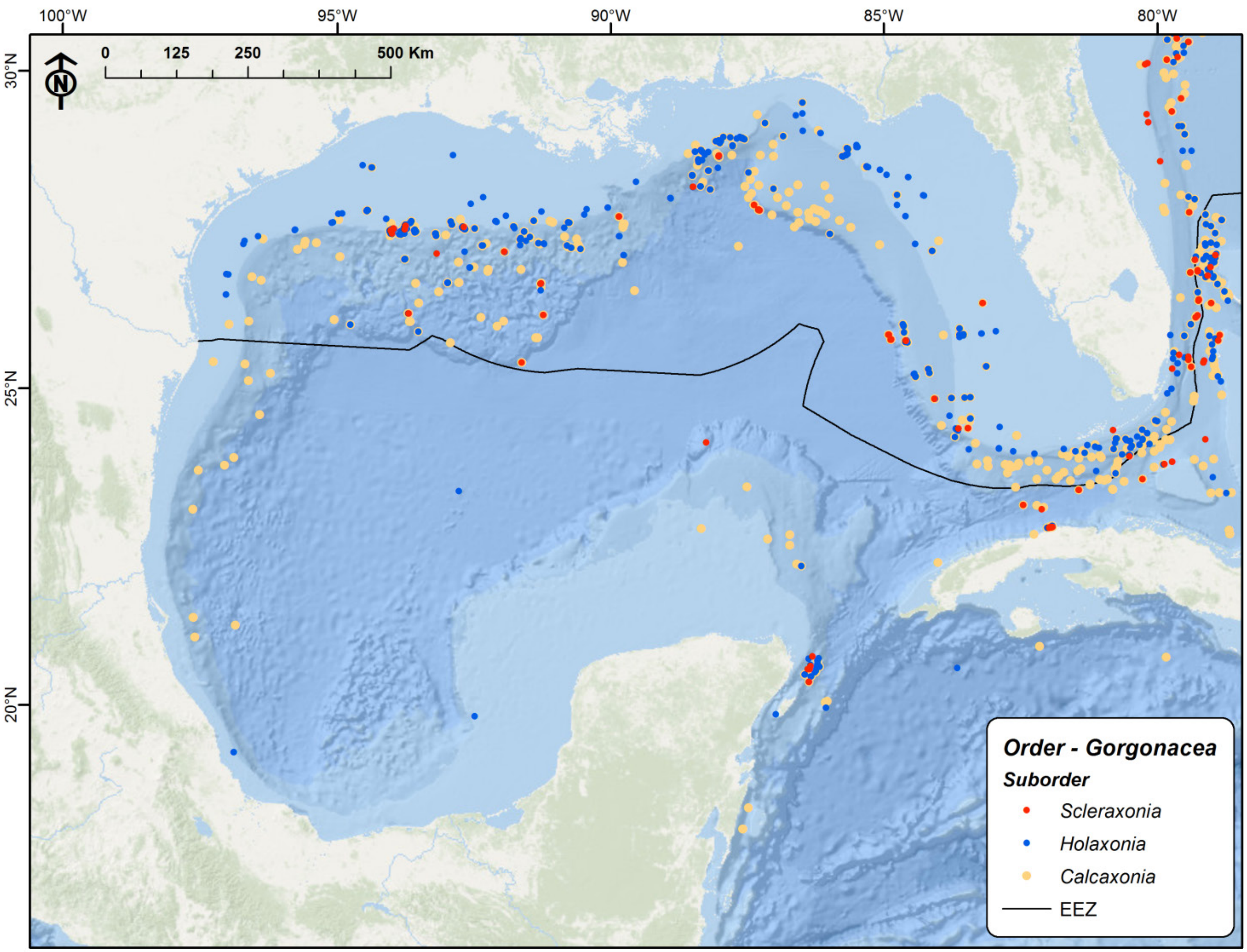
Map 1. *Locations of stony corals (Order Scleractinia) recorded in the National Deep-Sea Coral and Sponge Database (as of March 2016).*



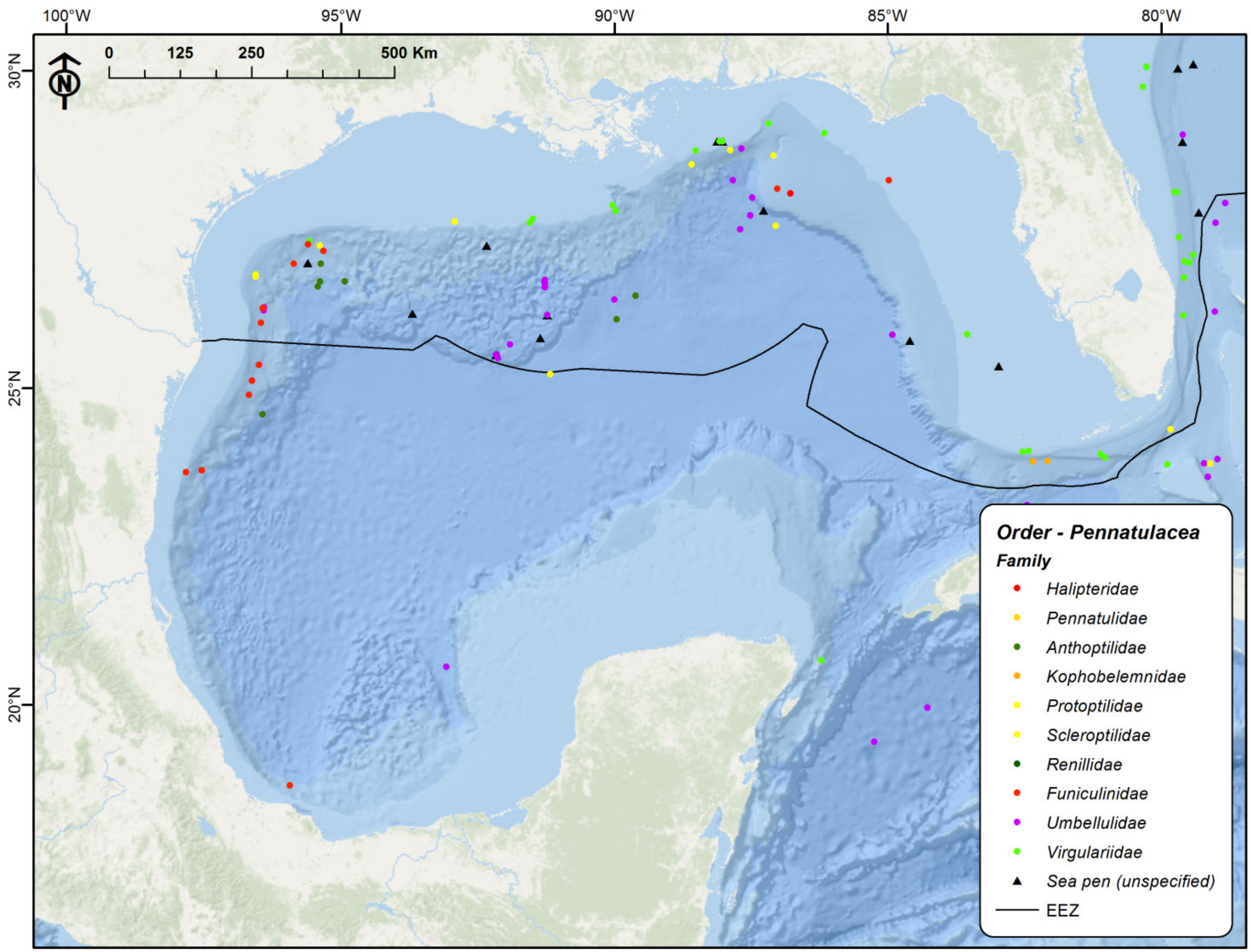
Map 2. *Locations of black corals (Order Antipatharia) recorded in the National Deep-Sea Coral and Sponge Database (as of March 2016).*



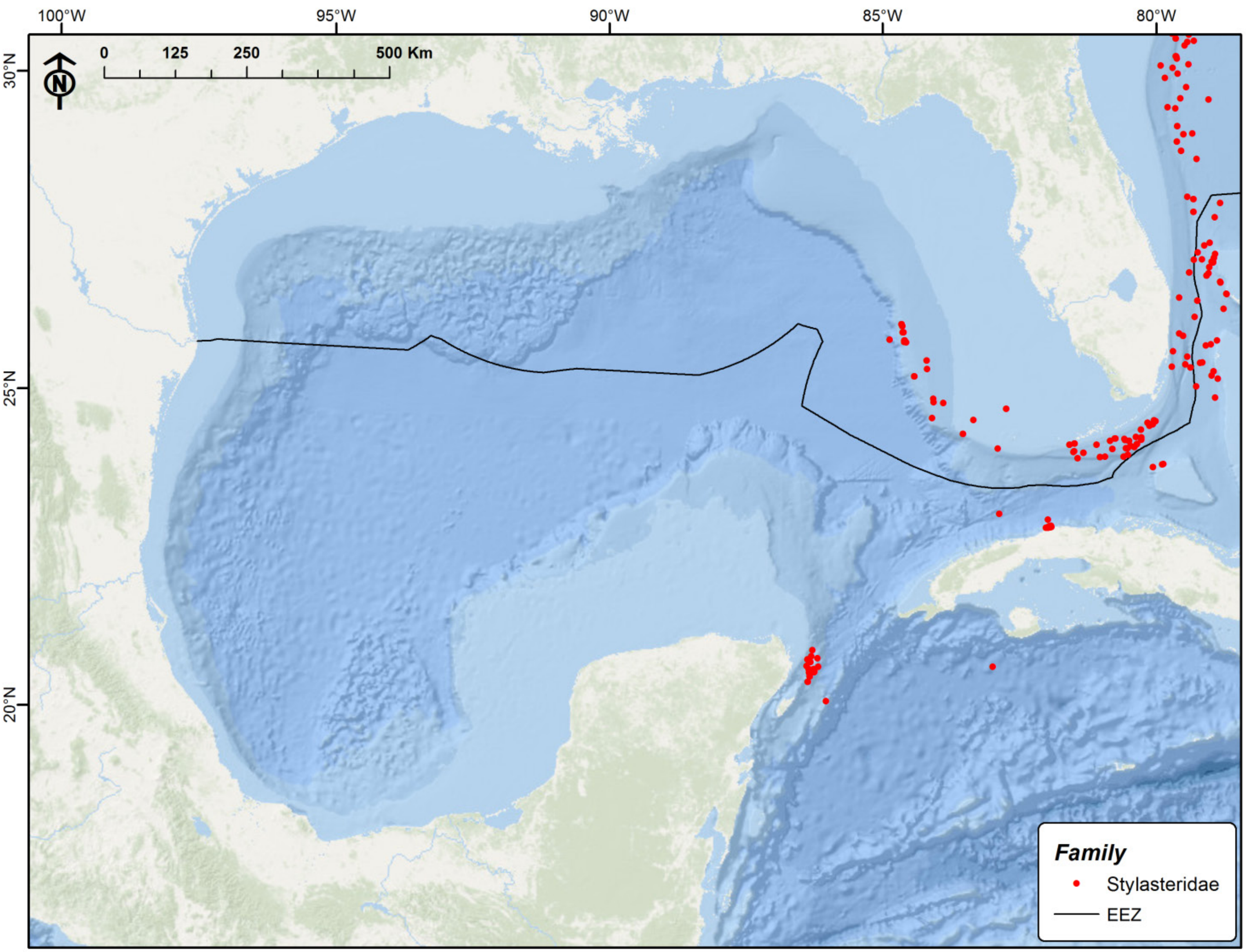
Map 3. *Locations of true soft corals (Order Alcyonacea) recorded in the National Deep-Sea Coral and Sponge Database (as of March 2016).*



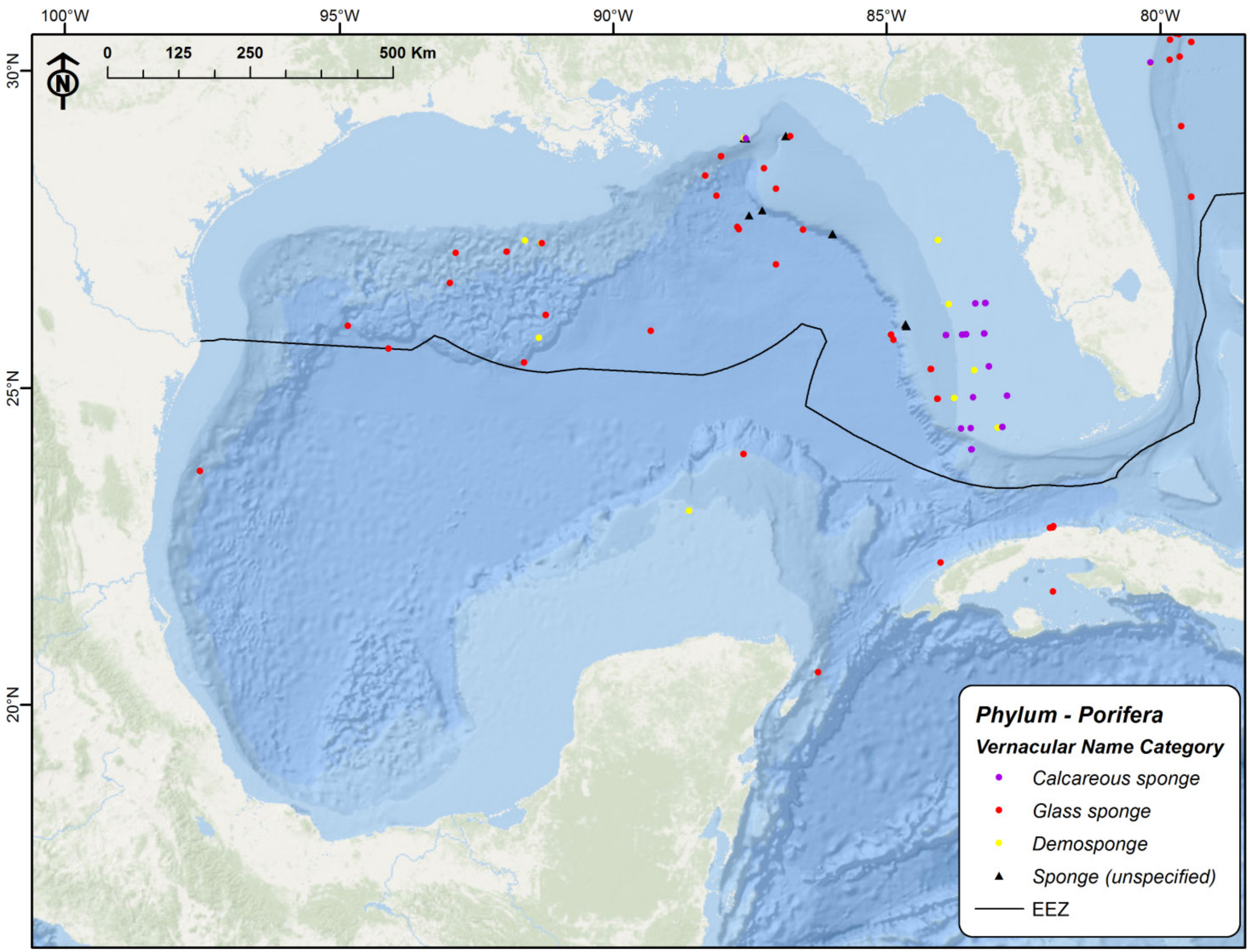
Map 4. *Locations of gorgonian corals (Order Gorgonacea) recorded in the National Deep-Sea Coral and Sponge Database (as of March 2016).*



Map 5. *Locations of sea pens (Order Pennatulacea) recorded in the National Deep-Sea Coral and Sponge Database (as of March 2016).*



Map 6. *Locations of lace corals (Order Stylasteridae) recorded in the National Deep-Sea Coral and Sponge Database (as of March 2016).*



Map 7. *Locations of sponges (Phylum Porifera) recorded in the National Deep-Sea Coral and Sponge Database (as of March 2016).*